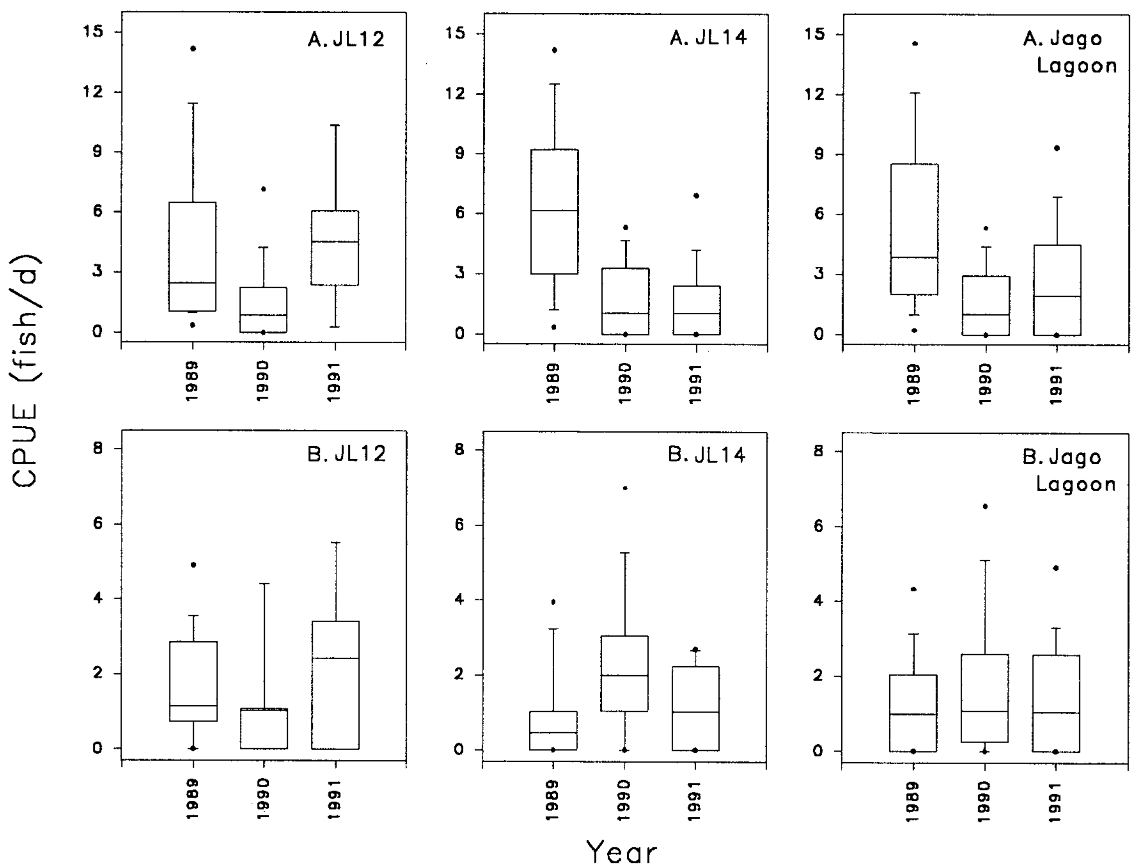

FIGURE 3.48.— Boxplots comparing daily CPUE (fish/d) observations among years for Arctic cisco > 200 mm FL in Jago Lagoon. A = time period 1, the first sampling day to July 31. B = time period 2, August 1 to August 14.

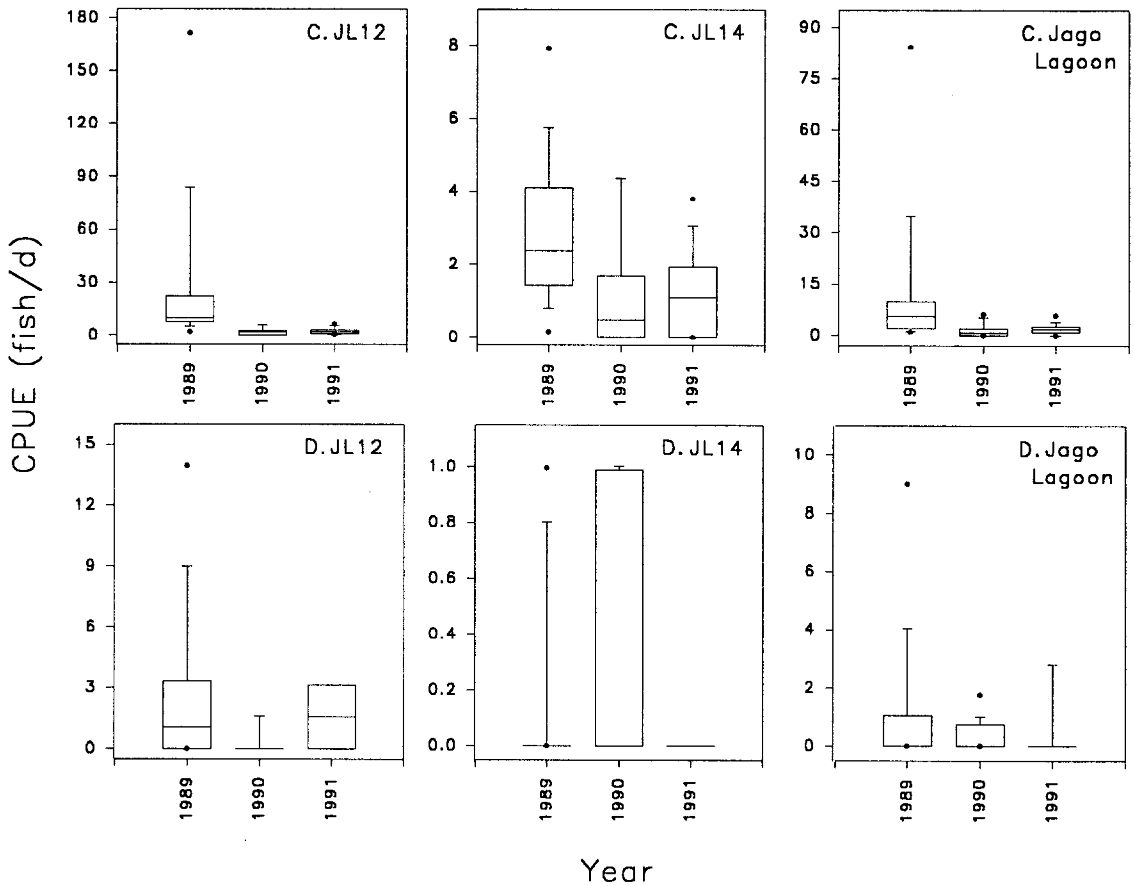

FIGURE 3.49.— Boxplots comparing daily CPUE (fish/d) observations among years for Arctic cisco > 200 mm FL in Jago Lagoon. C = time period 3, August 15 to August 31. D = time period 4, September 1 to the last sampling day.

TABLE 3.24.— Comparison of daily CPUE (fish/d) observations between years for Arctic cisco > 200 mm FL in Beaufort Lagoon. For each net station/sampling area those years with the same letter, within the same time period, are not significantly different (Kruskal-Wallis test with Scheffé multiple comparisons).

	Within location Scheffé groupings		
Year	BL02	BL04	Beaufort Lagoon
	Time Period 1 - first day to July 31		
1990	B	A	A
1991	A	A	A
	Time Period 2 - August 1 to August 14		
1990	B	B	B
1991	A	A	A
	Time Period 3 - August 15 to August 31		
1990	B	B	B
1991	A	A	A
	Time Period 4 - September 1 to last day		
1990	B	B	B
1991	A	A	A

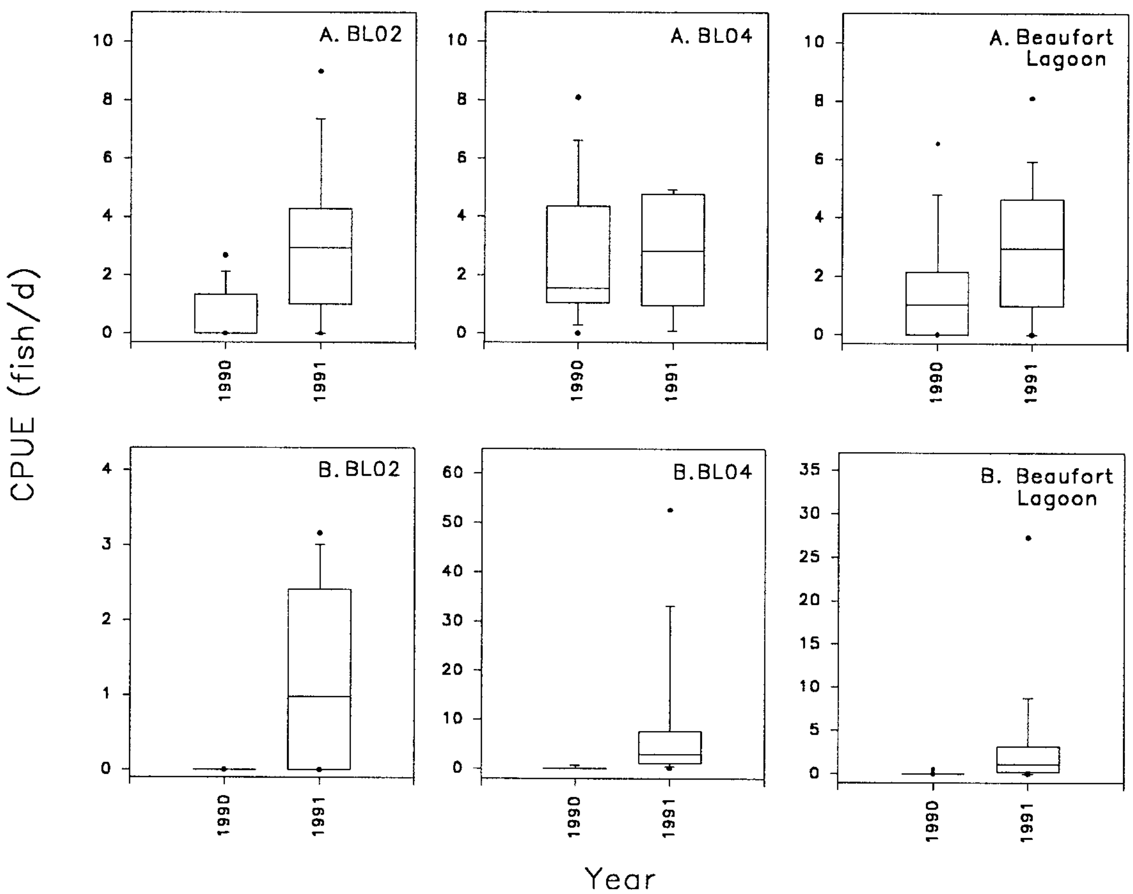

FIGURE 3.50.— Boxplots comparing daily CPUE (fish/d) observations between years for Arctic cisco > 200 mm FL in Beaufort Lagoon. A = time period 1, the first sampling day to July 31. B = time period 2, August 1 to August 14.

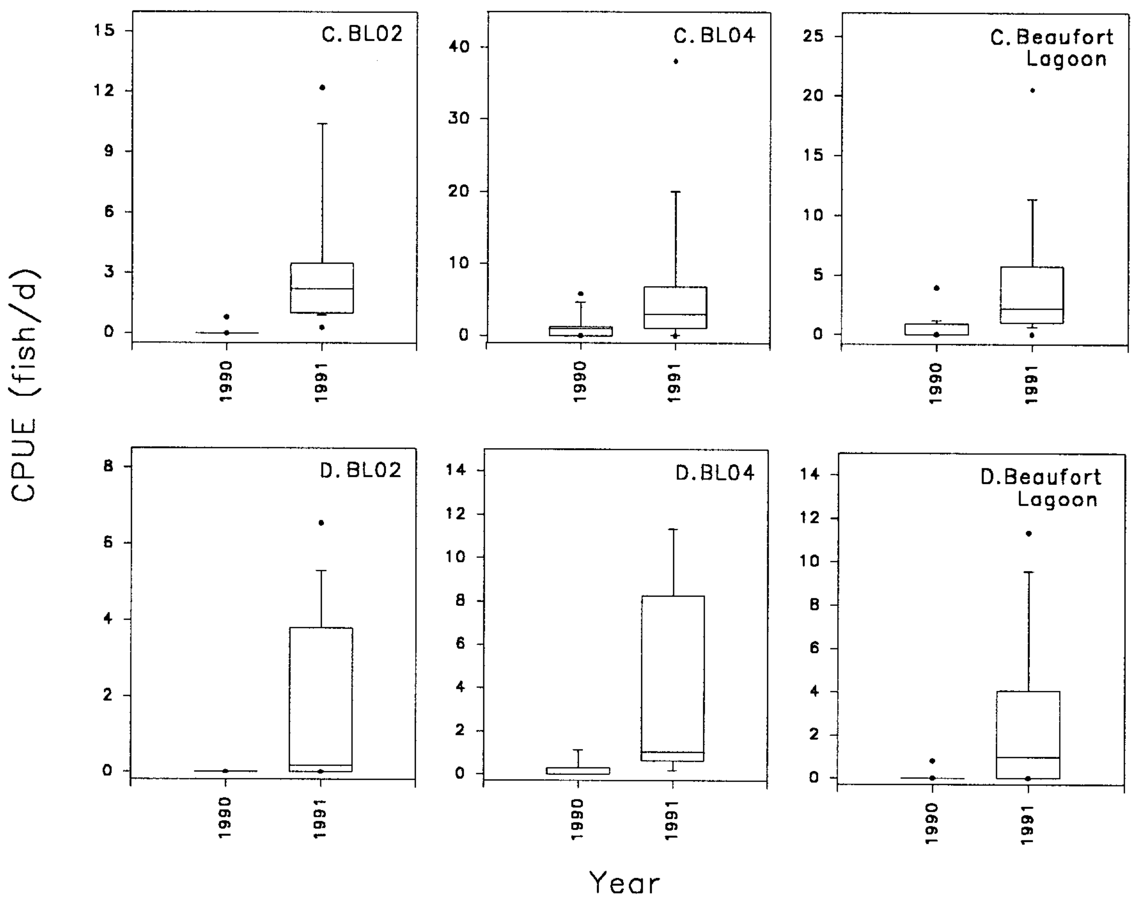

FIGURE 3.51.— Boxplots comparing daily CPUE (fish/d) observations between years for Arctic cisco > 200 mm FL in Beaufort Lagoon. C = time period 3, August 15 to August 31. D = time period 4, September 1 to the last sampling day.

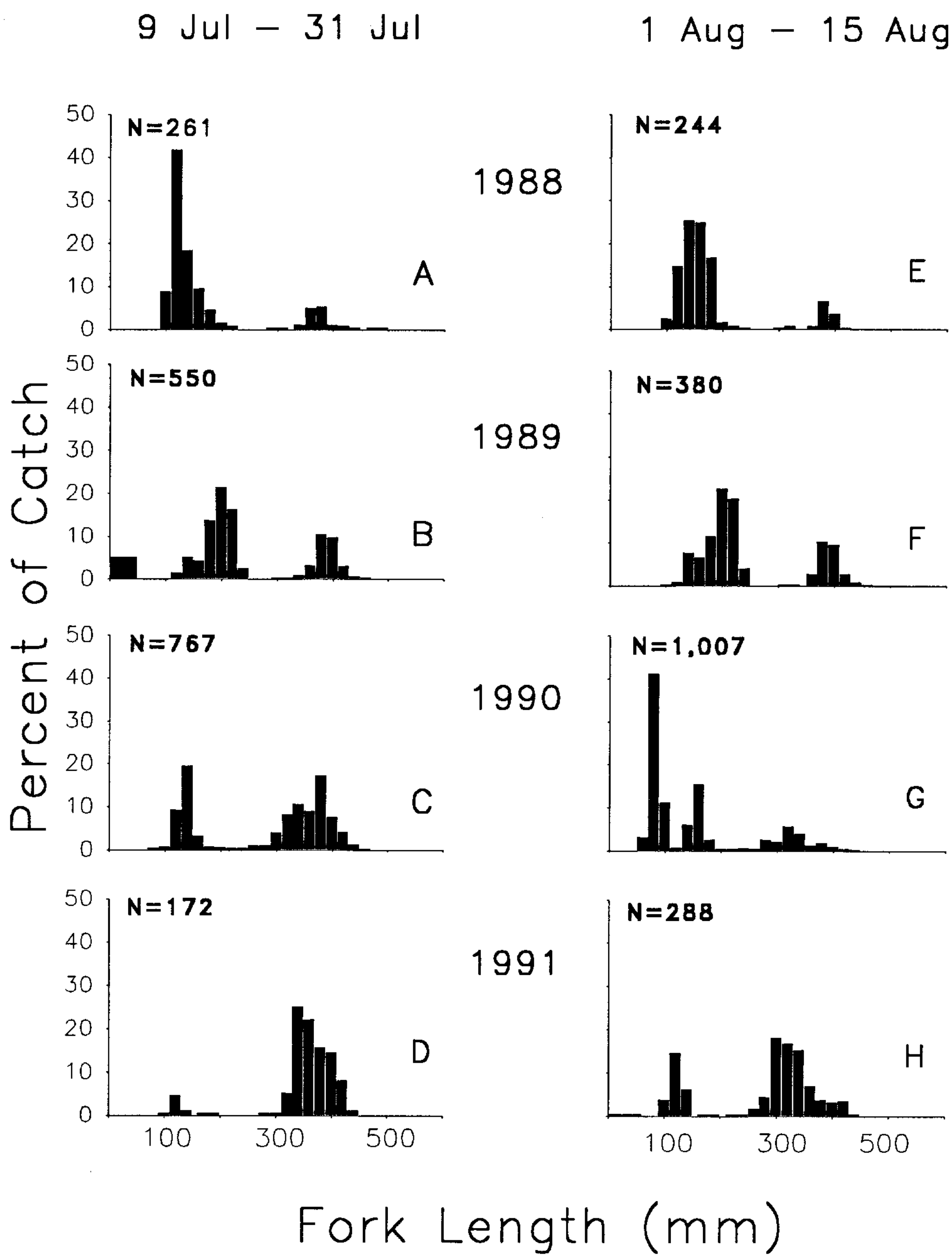

FIGURE 3.52.– Length frequencies of Arctic cisco captured by fyke nets in Simpson Cove, plotted by year for July 9 to August 15.

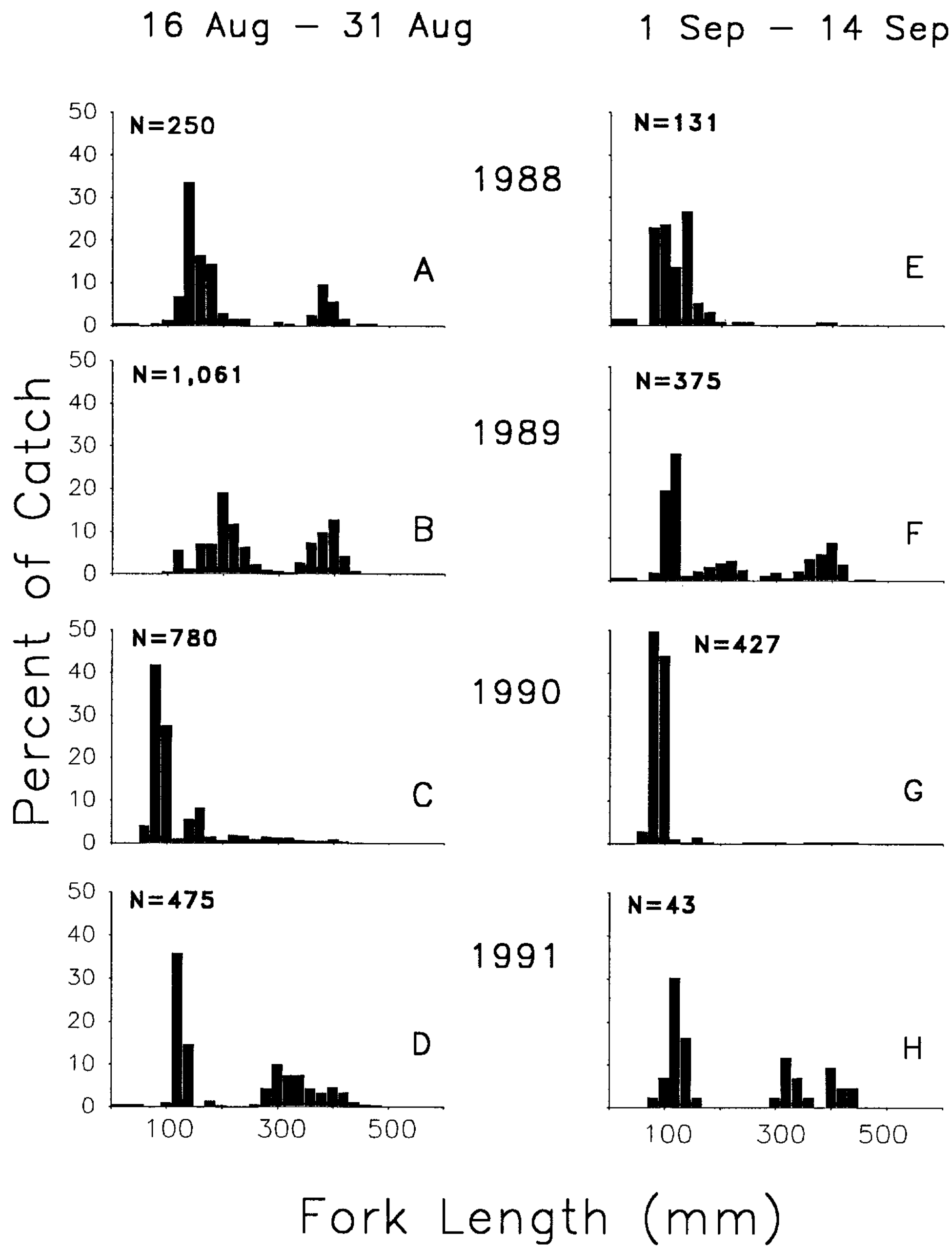

FIGURE 3.53.– Length frequencies of Arctic cisco captured by fyke nets in Simpson Cove, plotted by year for August 16 to September 14.

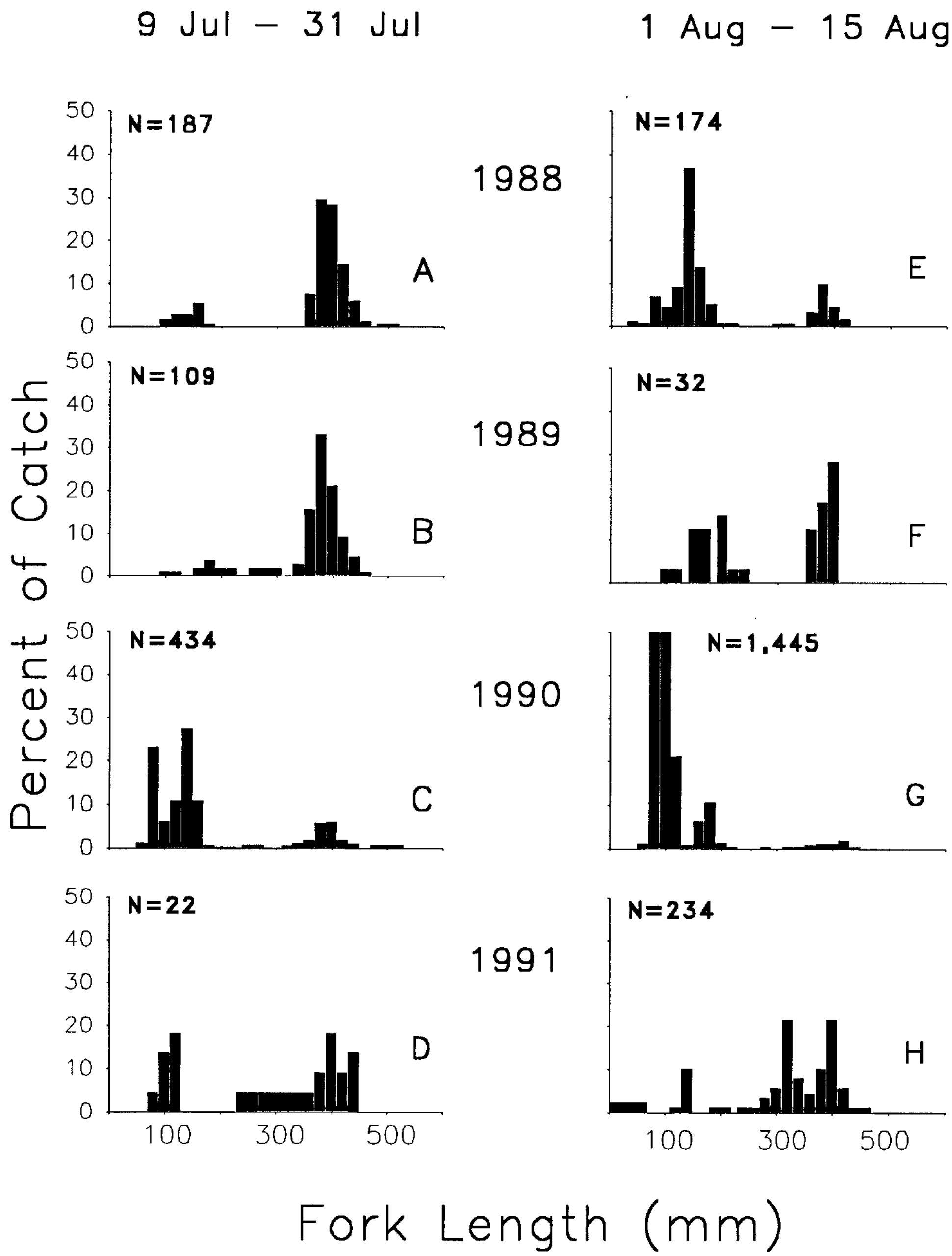

FIGURE 3.54.– Length frequencies of Arctic cisco captured by fyke nets in Kaktovik Lagoon, plotted by year for July 9 to August 15.

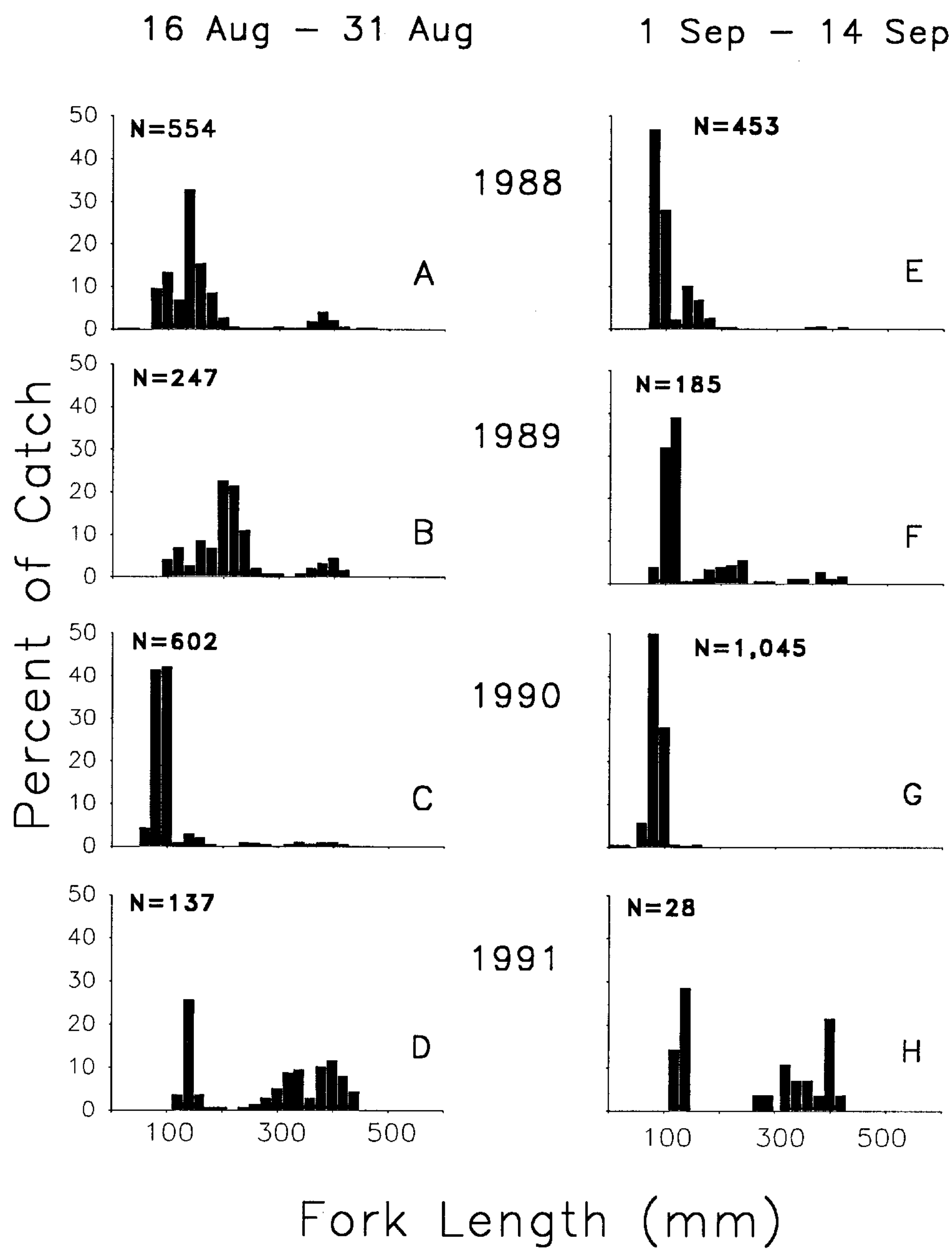

FIGURE 3.55.— Length frequencies of Arctic cisco captured by fyke nets in Kaktovik Lagoon, plotted by year for August 16 to September 14.

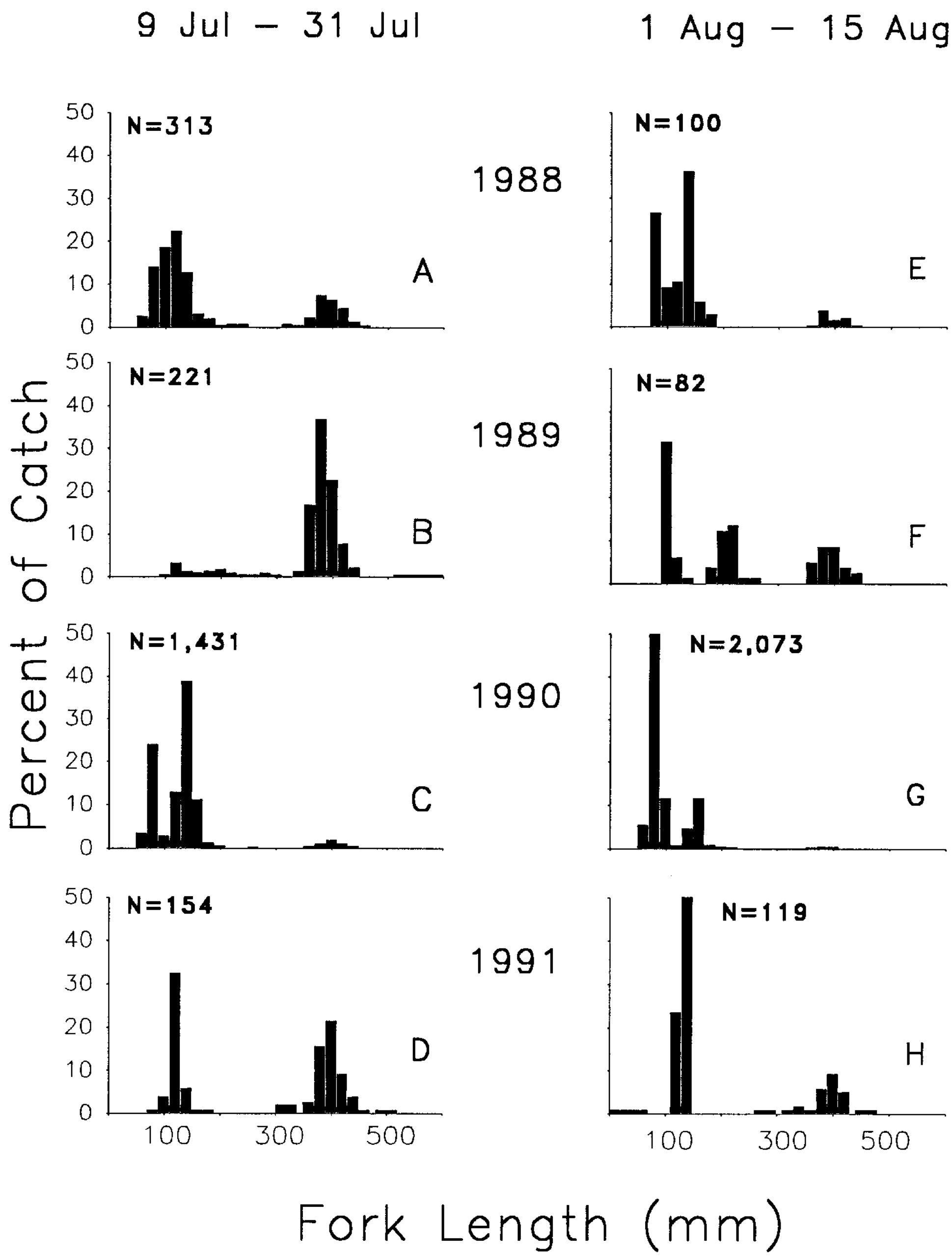

FIGURE 3.56.— Length frequencies of Arctic cisco captured by fyke nets in Jago Lagoon, plotted by year for July 9 to August 15.

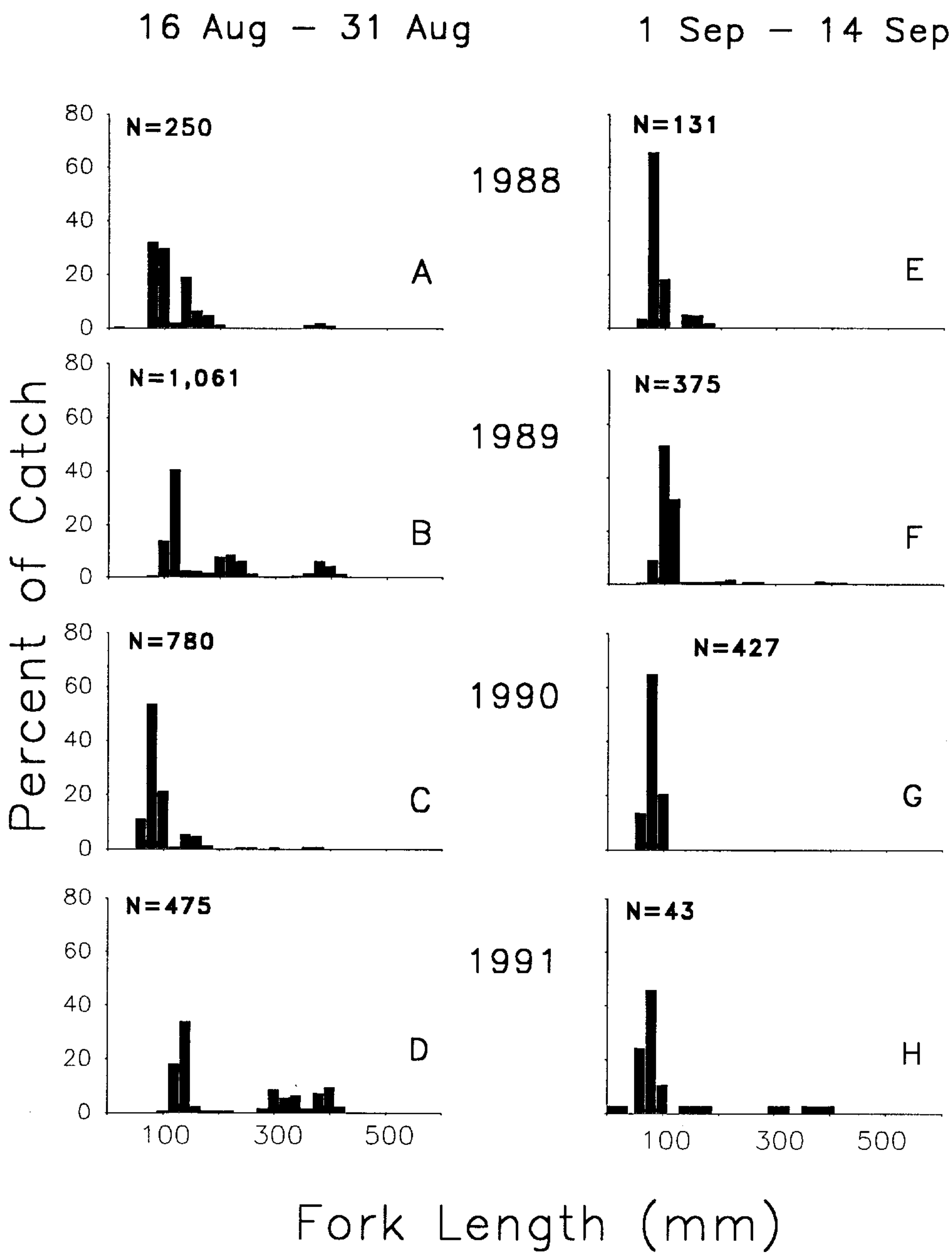

FIGURE 3.57.– Length frequencies of Arctic cisco captured by fyke nets in Jago Lagoon, plotted by year for August 16 to September 14.

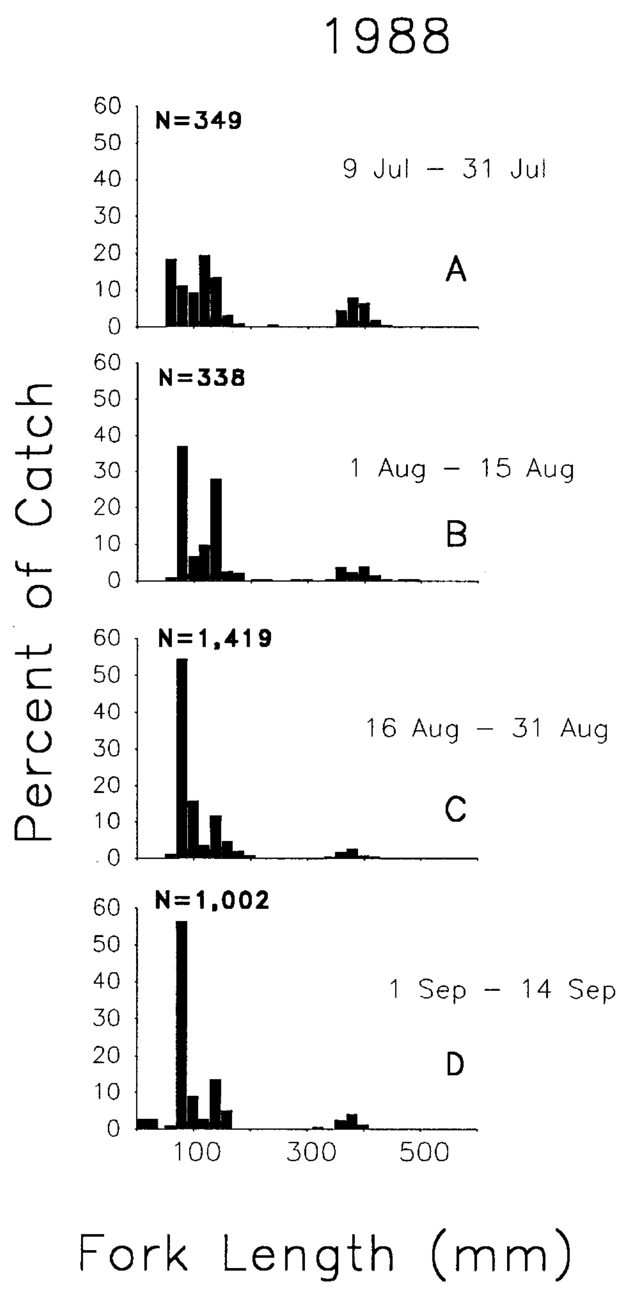

FIGURE 3.58.– Length frequencies of Arctic cisco captured by fyke nets in Pokok Bay, plotted for July 9 to September 14, 1988.

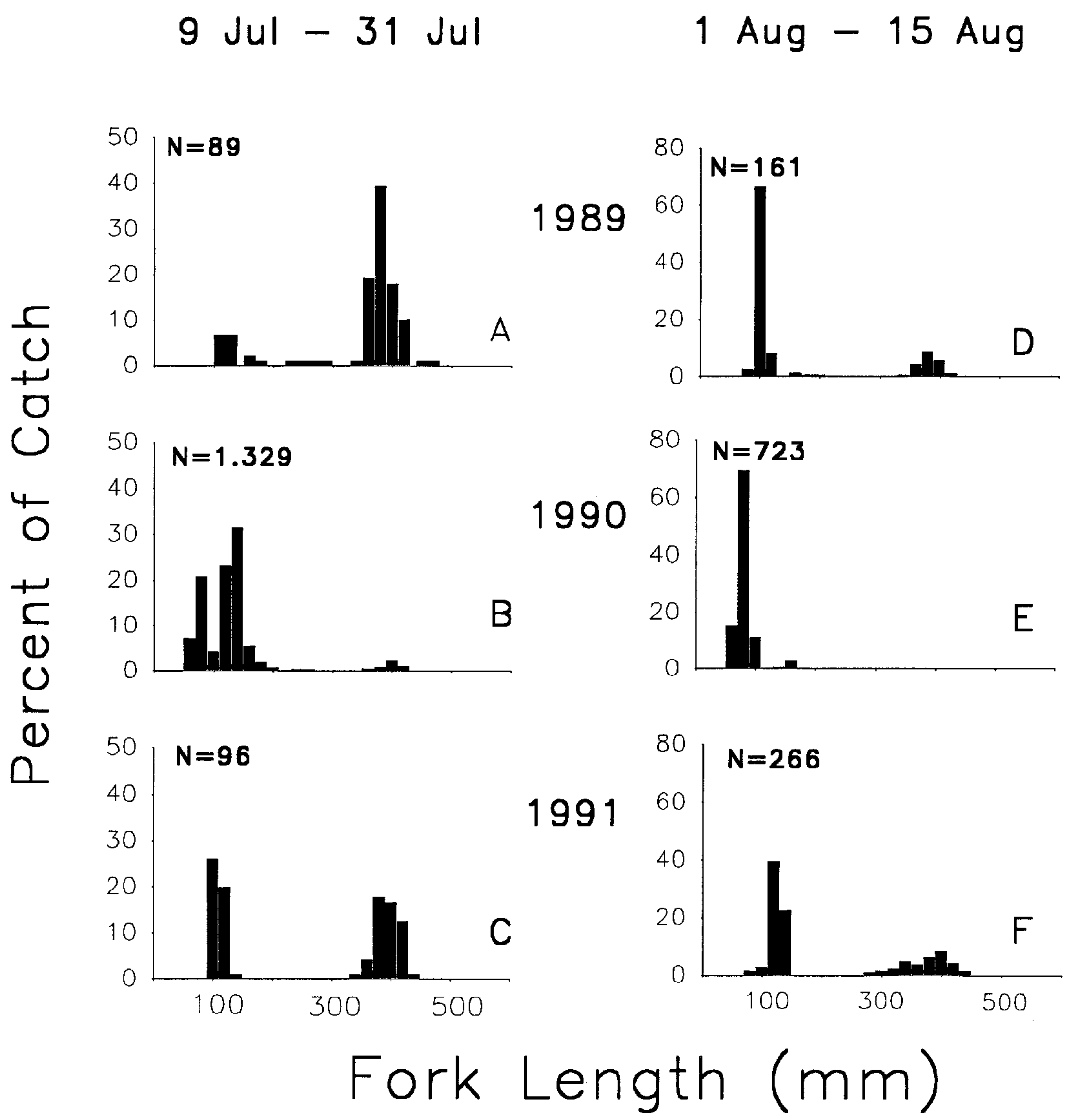

FIGURE 3.59.– Length frequencies of Arctic cisco captured by fyke nets in Beaufort Lagoon, plotted by year for July 9 to August 15.

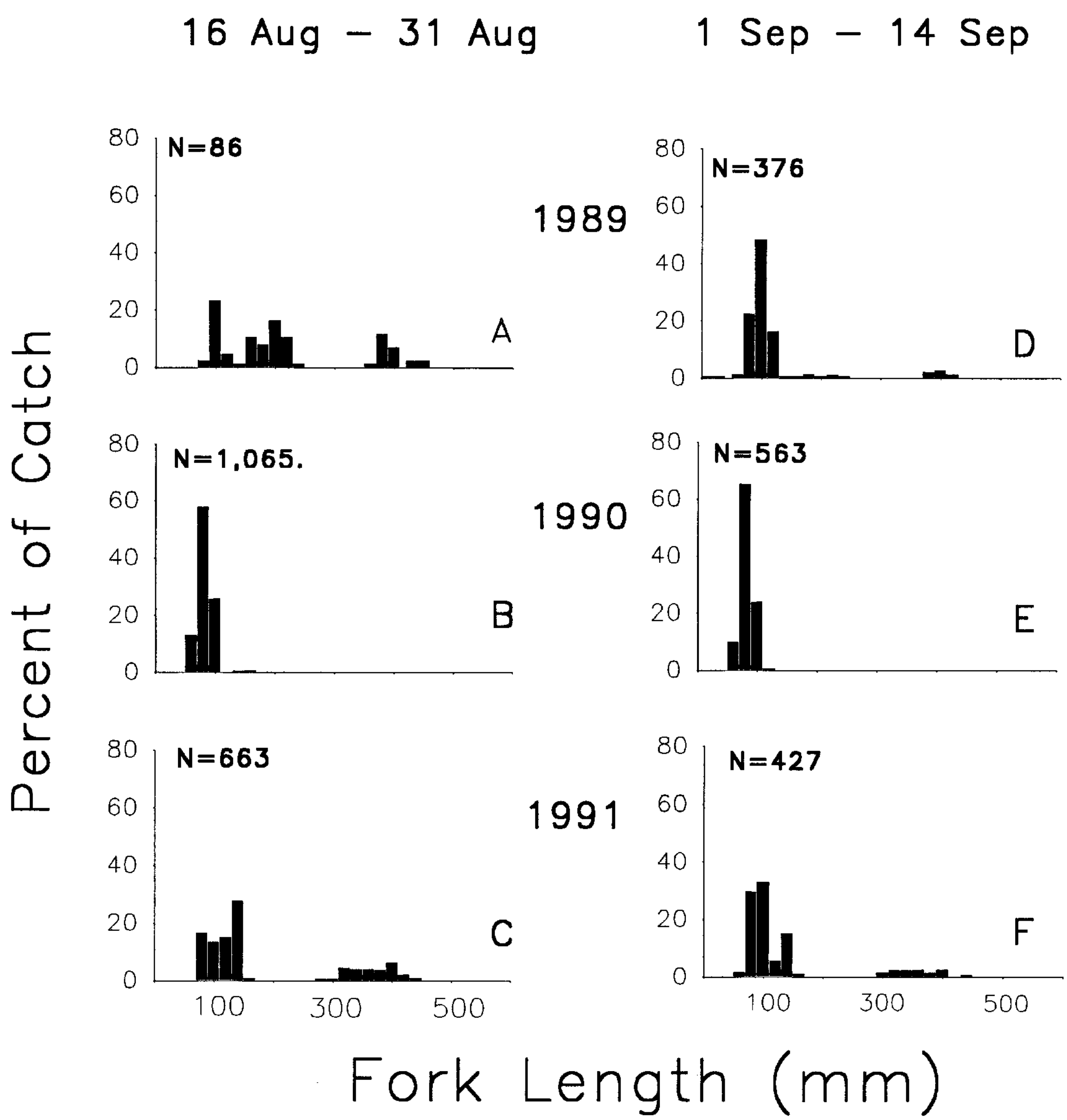

FIGURE 3.60.– Length frequencies of Arctic cisco captured by fyke nets in Beaufort Lagoon, plotted by year for August 16 to September 14.

July in 1989 (Figure 3.52B), and also in mid-August in 1988 and 1989 (Figures 3.53A, E). Arctic cisco between 100 and 200 mm FL were present during all time periods and years (Figures 3.52-3.53). In 1989, this mode appeared to be shifted to the right, i.e., larger fish, by approximately 50 mm. In 1990, nearly the entire catch during August and September fell within the first mode with a distinct lack of larger fish in the distributions.

Arctic cisco < 100 mm FL appeared the first two weeks in August in 1991 and in mid- to late August in 1988 (Figures 3.54H and 3.55A, respectively). Arctic cisco between 100 and 200 mm FL occurred throughout the sampling season (Figures 3.54-3.55). In 1989, the first mode occurred closer to 200 mm FL. In 1990, the first mode of lengths appeared to be 50-100 mm smaller than in other years. The second length mode of larger fish between 300 and 500 mm appeared between July 9 and August 15 and declined to almost zero fish by the last sampling period.

In Kaktovik Lagoon, few fish < 100 mm FL were present during the July sampling period in 1988 and 1989 (Figures 3.54A, B). A weak presence of Arctic cisco < 100 mm FL appeared the first two weeks in August in 1991 and in mid- to late August in 1988 (Figures 3.54H and 3.55A, respectively). Arctic cisco between 100 and 200 mm FL occurred throughout the sampling season (Figures 3.54-3.55). In 1989, the first mode occurred closer to 200 mm FL. In 1990, the first mode of lengths appeared to be 50-100 mm smaller than in other years. The second length mode of larger fish between 300 and 500 mm appeared between July 9 and August 15 and declined to almost zero fish by the last sampling period.

In Jago Lagoon the first mode between 50 and 150 mm FL was present during the first sampling period in July (this mode was very weak during the first period in 1989) and persisted throughout the sampling periods for all four years (Figures 3.56-3.57). Arctic cisco < 100 mm FL occurred between mid- and late August in 1988 and 1989, but not until after mid-August in 1991. The second length mode of larger fish between 300 and 500 mm appeared between early July and mid-August, although this mode was weak in 1990. As the sampling season progressed, the presence of these larger fish declined.

In Pokok Bay very small fish, < 100 mm FL, appeared between early and mid-September (Figure 3.58D). During 1988, Arctic cisco were observed at lengths between 50 and 150 mm with strong modes around 50 mm for the entire sampling season (Figure 3.58). The second mode of larger fish, between 300-500 mm FL, appeared by July 9 and remained throughout the sampling season.

In Beaufort Lagoon, the time of arrival of Arctic cisco < 100 mm FL was not indicated in the graphs. Arctic cisco between 50 and 150 mm FL and were present during all sampling periods and years (Figures 3.59-3.60). The second mode of fish between 300 and 500 mm FL appeared at the onset of sampling for all three years and declined or disappeared as the sampling season progressed to September 1.

Condition

Gender differences.– Condition analyses indicated that female Arctic cisco weighed more than males at a given length in July (Table 3.25). No significant differences were found in slope ($P = 0.13$), but intercepts differed ($P = 0.01$). Intercept values were higher for females regardless of the treatment of outliers. Plots of transformed data indicate that similar size ranges were available for each sex (Figures 3.61 A, B), but the distributions of fish lengths within the size range differed.

Seasonal differences.– Differences in condition were not found between fish sampled early and late during the sampling season, with years pooled, (slope $P = 0.77$ and intercept $P = 0.90$) and outliers retained (Table 3.26). When outliers were excluded, however, differences in condition were noted (slope $P = 0.36$ and intercept $P = 0.0001$). Fish sample in July weighed more at a given length than fish sampled in September. Plots of transformed data indicated that the distribution of (Figure 3.61) fish lengths varied only slightly by sampling season.

Results were mixed within individual years. In 1988, a significant difference in slope precluded statements about fish condition. Results from 1989 and 1991 were similar to the pooled year results. In 1990, interpretations differed depending on the treatment of outliers; no difference in condition occurred if outlier were retained, but slope differences occurred when outliers were discarded.

Overwintering.– When outliers were retained, no changes in condition were detected over the three separate winters sampled (Table 3.27). Various changes in slope and intercept were detected when outliers were removed from the analyses. Of the latter, only samples spanning the winter of 1989-90 indicated a change in condition (slope $P = 0.89$ and intercepts $P = 0.0001$). Fish weighed more at a given length in the fall of 1989 than fish the following spring. Plots of transformed data indicated that samples differed between the fall and the following spring (Figure 3.62).

Spatial differences.– In July, with years pooled, slope estimates were significantly different precluding statements about condition (Table 3.28) among the sampling areas despite the treatment of outliers. Plots of transformed data indicated that length frequencies of sampled fish varied between areas (Figure 3.63). Locations of clustered observations in the distributions differed as well as overall size ranges represented. In individual years, sample sizes in some areas were too small to be included in the analyses. Slope differences in 1989 and 1990 precluded comparisons of condition. In 1991, no difference in condition was detected with outliers retained or slope differences precluded statements about condition when outliers were discarded.

In contrast, condition of Arctic cisco sampled after August 27 differed among areas: slope $P = 0.10$ and intercept $P = 0.02$, outliers retained (Table 3.29). Pairwise comparisons indicated that Kaktovik and Jago lagoon samples were different than the other areas. Intercept values indicated that Arctic cisco found in the Kaktovik and Jago area were of higher condition. Removal

TABLE 3.25.— Condition comparisons between female and male Arctic cisco collected in July, 1988-91. Analyses were done for pooled years and within an individual year. Asterisks (*) indicate significant differences in condition.

Group	N	Slopes		Intercepts		
		b(SE)	P-values	$\log_e a$(SE)	P-values	r^2
Females	62	3.12 (0.07)		-12.21 (0.38)		0.97
Males	91	3.23 (0.03)		-12.76 (0.20)		0.99
			P = 0.13		P = 0.01	*
	Without outliers		P = 0.07		P = 0.01	*

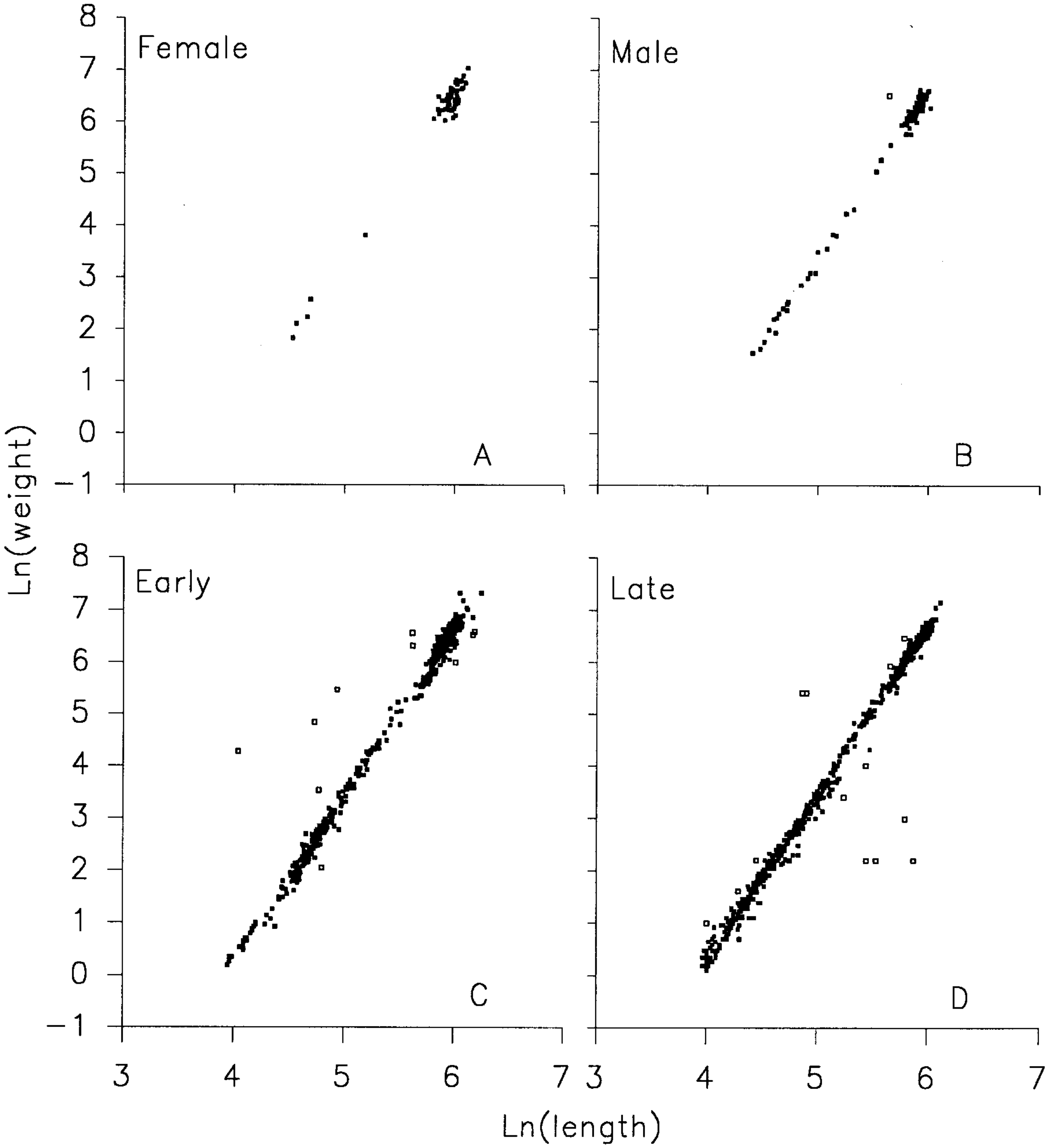

FIGURE 3.61.— Log-transformed weight-length data (□ = Outliers) for comparisons between sexes (A, B) in July and between seasons (C, D). Seasonal data correspond to early (July 9-31) and late (August 27-September 14) sampling periods.

TABLE 3.26.— Seasonal fish condition comparisons for Arctic cisco for all years combined and for individually sampled years. Asterisks (*) indicate significant changes in condition.

		Slopes		Intercepts		
Group	N	b(SE)	P-values	$\log_e a$(SE)	P-values	r^2
			All years			
Early	569	3.18 (0.02)		-12.49 (0.10)		0.98
Late	581	3.17 (0.02)		-12.45 (0.10)		0.97
			P = 0.77		P = 0.90	
Without outliers			P = 0.36		P = 0.0001	*
			1988			
Early	37	3.27 (0.04)		-13.05 (0.24)		0.99
Late	35	3.45 (0.07)		-14.09 (0.35)		0.98
			P = 0.02		P = 0.26	
Without outliers			P = 0.03		P = 0.02	
			1989			
Early	82	3.14 (0.03)		-12.31 (0.12)		0.99
Late	139	3.13 (0.06)		-12.21 (0.43)		0.91
			P = 0.92		P = 0.55	
Without outliers			P = 0.051		P = 0.0001	*
			1990			
Early	328	3.17 (0.03)		-12.41 (0.14)		0.98
Late	156	3.12 (0.34)		-12.19 (0.18)		0.98
			P = 0.35		P = 0.78	
Without outliers			P = 0.0009		P = 0.0035	
			1991			
Early	122	3.21 (0.04)		-12.68 (0.22)		0.98
Late	251	3.19 (0.03)		-12.53 (0.14)		0.98
			P = 0.67		P = 0.28	
Without outliers			P = 0.13		P = 0.0006	*

TABLE 3.27.— Condition comparisons in overwintering Arctic cisco for the winters of 1988-89, 1989-90, and 1990-91. Asterisks (*) indicate significant changes in condition.

		Slopes		Intercepts		
Group	N	b(SE)	P-values	$\log_e a$(SE)	P-values	r^2
			1988 - 1989			
Fall	83	3.42 (0.07)		-13.96 (0.37)		0.99
Spring	82	3.14 (0.03)		-12.31 (0.17)		0.99
			P = 0.001		P = 0.001	
	Without outliers		P = 0.0001		P = 0.0001	
			1989 - 1990			
Fall	140	3.14 (0.08)		-12.29 (0.42)		0.92
Spring	329	3.17 (0.02)		-12.41 (0.14)		0.98
			P = 0.70		P = 0.056	
	Without outliers		P = 0.89		P = 0.0001	*
			1990 - 1991			
Fall	157	3.13 (0.04)		-12.23 (0.18)		0.98
Spring	122	3.21 (0.04)		-12.68 (0.22)		0.98
			P = 0.15		P = 0.29	
	Without outliers		P = 0.001		P = 0.0005	

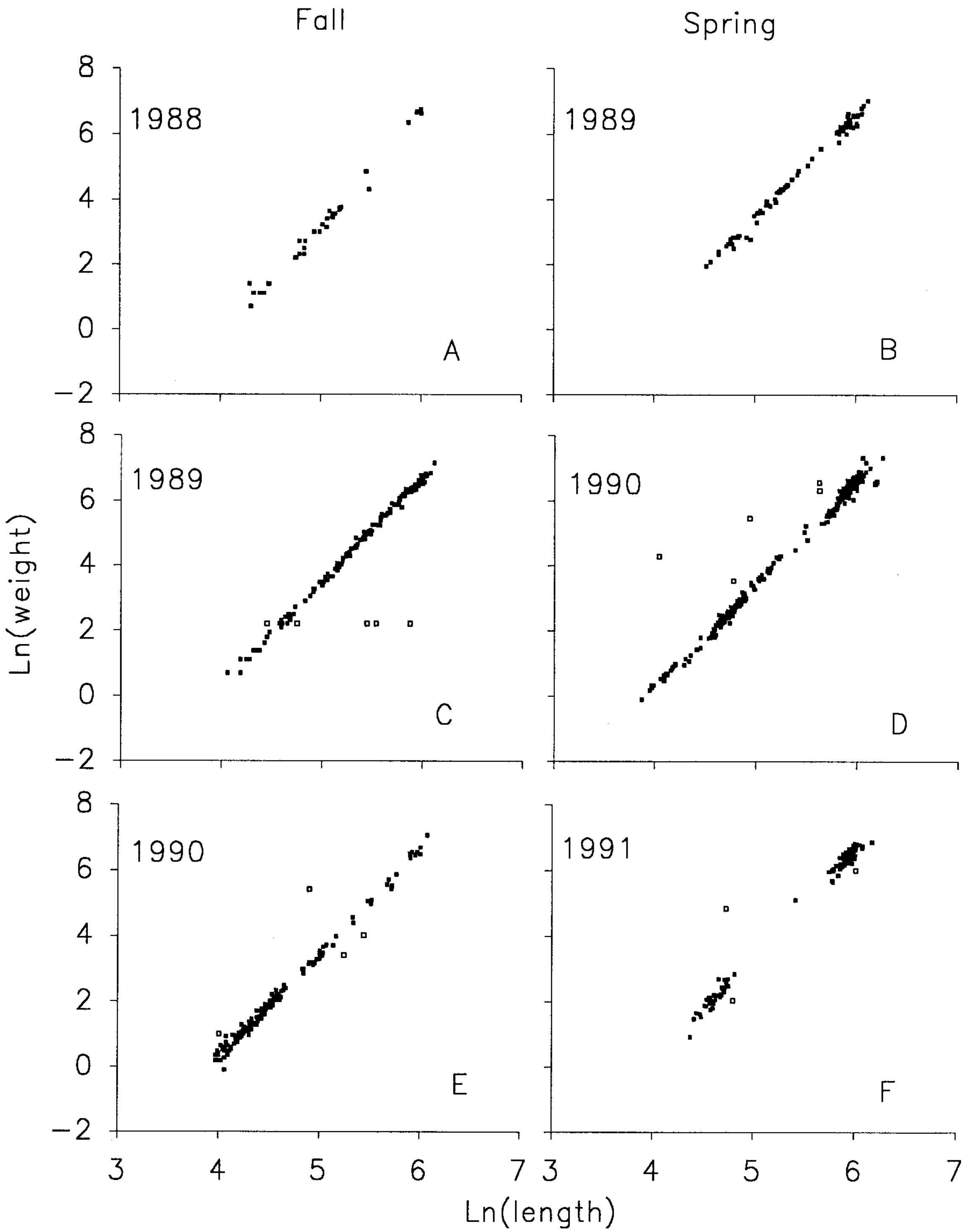

FIGURE 3.62.— Log-transformed weight-length data (□ = outliers) for three comparisons, winters 1988-89, 1989-90, and 1990.

TABLE 3.28.— Spatial condition comparisons for Arctic cisco collected in July for all years combined and sampled years individually. In 1988 sample sizes were too small to analyze separately, but were included in the overall analyses. Asterisks(*) indicate significant differences in condition.

		Slopes		Intercepts			
Group	N	b(SE)	*P*-values	$\log_e a$(SE)	*P*-values	r^2	Pairwise results
			All Years				
Beaufort Lagoon	113	3.08(0.06)		-11.91(0.31)		0.96	
Kaktovik/Jago	223	3.20(0.02)		-12.61(0.09)		0.99	
Simpson Cove	233	3.27(0.03)		-12.97(0.17)		0.98	
			P = 0.0006		P = 0.0748		
Without outliers			P = 0.0001		P = 0.2041		
			1989				
Kaktovik/Jago	48	3.09(0.04)		-12.09(0.21)		0.99	
Simpson Cove	34	3.32(0.08)		-13.24(0.41)		0.98	
			P = 0.01		*P* = 0.34		
Without outliers			*P* = 0.01		*P* = 0.34		
			1990				
Beaufort Lagoon	64	3.08(0.08)		-11.87(0.44)		0.96	
Kaktovik/Jago	135	3.21(0.02)		-12.64(0.10)		0.99	
Simpson Cove	129	3.23(0.05)		-12.76(0.97)		0.97	
			P = 0.0468		*P* = 0.24		
Without outliers			*P* = 0.0017		*P* = 0.0001		
			1991				
Beaufort Lagoon	49	3.09(0.07)		-12.00(0.40)		0.97	
Simpson Cove	50	3.30(0.07)		-13.19(0.42)		0.98	
			P = 0.109		*P* = 0.64		
Without outliers			*P* = 0.022		*P* = 0.0045		

of outliers from the analysis changed the interpretation, because the differences in slope precluded statements about condition. Plots of transformed data showed some differences in the distribution of observed lengths (Figure 3.63), particularly with the discontinuous nature of the Beaufort Lagoon sample. Within years, interpretation of results were precluded by inadequate sample sizes (1988) and changes in slope, or differences were not significant.

Annual differences.— Among year comparisons of condition in July, areas pooled, indicated significant differences: slope $P = 0.54$ and intercept $P = 0.03$, outliers retained (Table 3.30). Pairwise comparisons showed that condition in 1988 differed from that in 1990, but no other pairs differed. Intercept values indicated that Arctic cisco condition was higher in 1990 than in 1988. Plots of transformed data showed the degree of clustering differed yearly (Figure 3.64). Within individual areas no differences in condition were detected among years in Beaufort Lagoon or Simpson Cove. Differences in slope precluded statements about condition of Arctic cisco from Kaktovik and Jago lagoons.

Slope differences preclude statements about condition for pooled data collected from the three areas after August 27, although criteria were nearly met to accept that slopes were equal and condition differed yearly: slope $P = 0.049$ and intercept $P = 0.0001$ (Table 3.31). Plots of transformed data highlight differences in the data sets such as a discontinuous distribution in 1991 and shorter range of lengths in 1988 (Figure 3.65). Within areas, no difference in condition was detected in Beaufort Lagoon. Differences in condition were found in Kaktovik and Jago lagoons when outliers were discarded. However, low r^2 values, high standard errors and high intercept values in 1989 suggest that these results may be spurious. In 1991, condition was low in Simpson Cove when outliers were retained.

Age and Growth

Arctic cisco collected during July in the years 1988-91 ranged in age from 0 to 13 years (Table 3.32). Age-1 occurred most frequently (27%, N = 137), with age-2 being the second most frequent age (23%, $N = 112$), and age-0 the third most frequent age (13%, $N = 64$). The mean age was 3.3 years ($N = 516$) and the mean length was 191 mm FL. Overlap of length ranges between ages was considerable beyond age 4. Growth rate, as indicated by the shape of the growth curve (Figure 3.66A) increased steadily until age-6. At that age, growth appeared to level off with only a slight increase until age-13.

Among areas, differences in mean lengths at age occurred only at age-4 when the mean was smaller in Simpson Cove than in either Jago or Beaufort lagoons (Table 3.33). However, small sample sizes make the validity of this comparison tenuous.

Among years, differences in mean lengths occurred at age-1 and age-2 (Table 3.34). At age-1, mean lengths were similar during 1988-90. In 1991, mean lengths were similar to 1988, but smaller than in the other years. At age-2, mean lengths were similar during 1988-90. In 1991, mean lengths were similar to those in 1988 and 1990, but smaller than those in 1989. As with the case

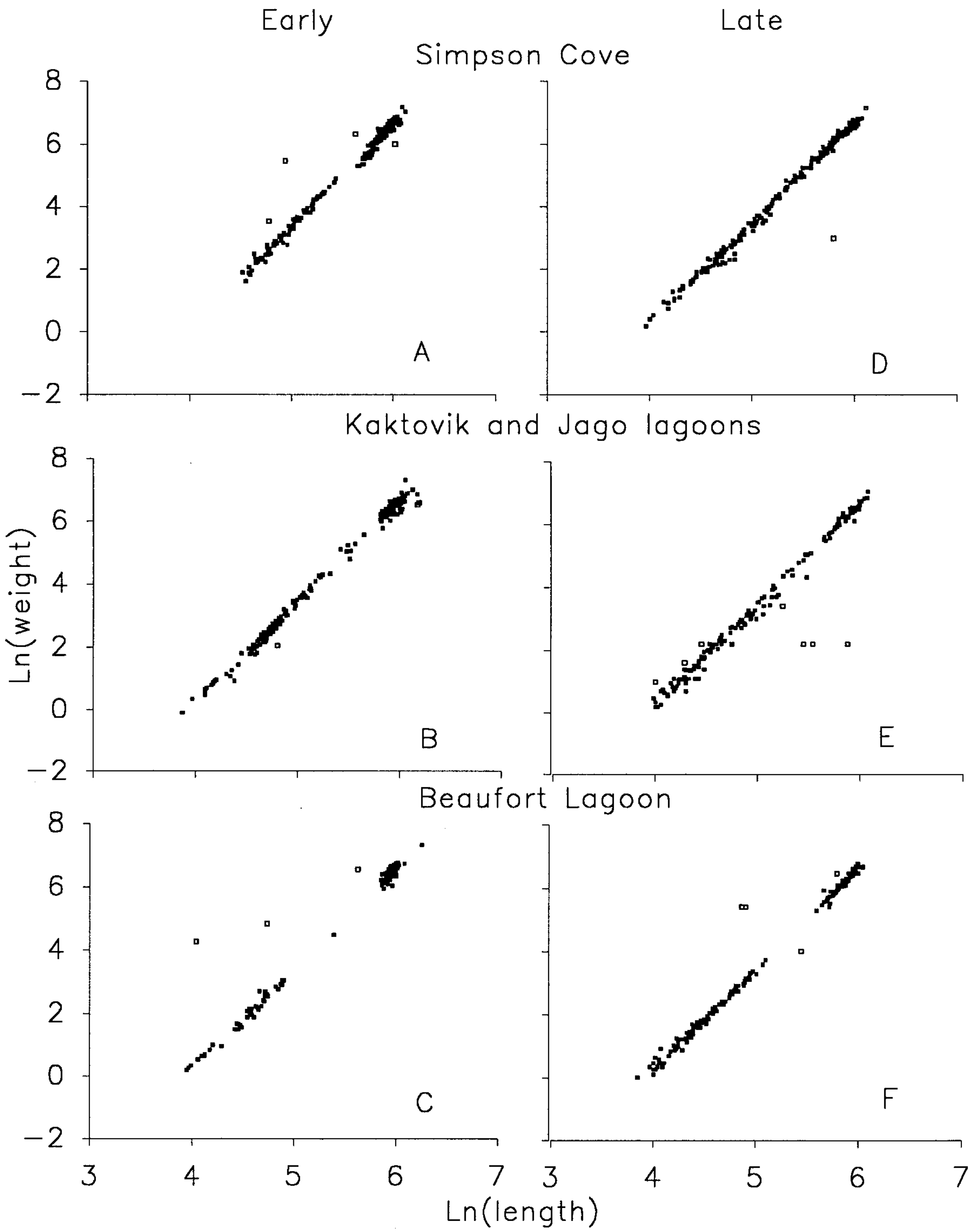

FIGURE 3.63.— Log-transformed weight-length data (□ = Outlier) for among-area comparisons, early (July, first column) and late (after August 27, second column) of each year. Plots are compared down the columns.

TABLE 3.29.— Spatial condition comparisons for Arctic cisco collected after August 27 for all years combined and 1991. Asterisks (*) indicate significant changes in condition.

Group	N	Slopes: b(SE)	Slopes: P-values	Intercepts: $\log_e a$(SE)	Intercepts: P-values	r^2	Pairwise results
All years							
Beaufort Lagoon	179	3.17 (0.03)		-12.41 (0.15)		0.98	A
Kaktovik/Jago Lagoon	171	3.11 (0.06)		-12.18 (0.06)		0.95	B
Simpson Cove	223	3.22 (0.03)		-12.69 (0.14)		0.98	A
			$P = 0.10$		$P = 0.02$	*	
Without outliers			$P = 0.02$		$P = 0.32$		
1989							
Kaktovik/Jago	40	2.76 (0.23)		-10.57 (1.16)		0.78	
Simpson Cove	100	3.21 (0.02)		-12.58 (0.13)		0.99	
			$P = 0.0085$		$P = 0.0007$		
Without outliers			$P = 0.35$		$P = 0.26$		
1990							
Beaufort Lagoon	51	3.09 (0.10)		-12.06 (0.47)		0.95	
Kaktovik/Jago Lagoon	68	3.16 (0.04)		-12.37 (0.18)		0.99	
Simpson Cove	38	3.12 (0.05)		-12.17 (0.23)		0.99	
			$P = 0.72$		$P = 0.99$		
Without outliers			$P = 0.01$		$P = 0.32$		
1991							
Beaufort Lagoon	128	3.18 (0.03)		-12.47 (0.16)		0.99	
Kaktovik/Jago Lagoon	41	3.18 (0.03)		-12.47 (0.18)		0.99	
Simpson Cove	82	3.23 (0.07)		-12.80 (0.36)		0.97	
			$P = 0.74$		$P = 0.13$		
Without outliers			$P = 0.003$		$P = 0.25$		

TABLE 3.30.– Annual condition comparisons for Arctic cisco collected in July for all sampling areas combined and sampling areas individually. Within individual sampling areas some years were dropped from the analyses if sample sizes were below the minimum (N=32). Asterisks (*) indicate significant changes in condition.

Group	N	Slopes b(SE)	Slopes P-values	Intercepts $\log_e a$(SE)	Intercepts P-values	r^2	Pairwise Results
All Areas							
1988	37	3.27 (0.04)		-13.05 (0.24)		0.99	A
1989	82	3.14 (0.03)		-12.31 (0.17)		0.99	A,B
1990	328	3.17 (0.02)		-12.41 (0.14)		0.99	B
1991	122	3.21 (0.04)		-12.68 (0.22)		0.98	A,B
			P = 0.54		P = 0.03	*	
	Without outliers		P = 0.032		P = 0.0003		
Beaufort Lagoon							
1990	64	3.08 (0.08)		-11.87 (0.44)		0.96	
1991	49	3.09 (0.07)		-12.00 (0.40)		0.97	
			P = 0.92		P = 0.46		
	Without outliers		P = 0.34		P = 0.13		
Kaktovik/Jago lagoons							
1989	48	3.09 (0.04)		-12.00 (0.21)		0.99	
1990	135	3.21 (0.02)		-12.64 (0.10)		0.99	
			P = 0.005		P = 0.055		
	Without outliers		P = 0.0002		P = 0.0031		
Simpson Cove							
1989	34	3.32 (0.08)		-13.24 (0.41)		0.98	
1990	129	3.23 (0.05)		-12.76 (0.27)		0.97	
1991	50	3.30 (0.07)		-13.19 (0.42)		0.97	
			P = 0.67		P = 0.95		
	Without outliers		P = 0.89		P = 0.14		

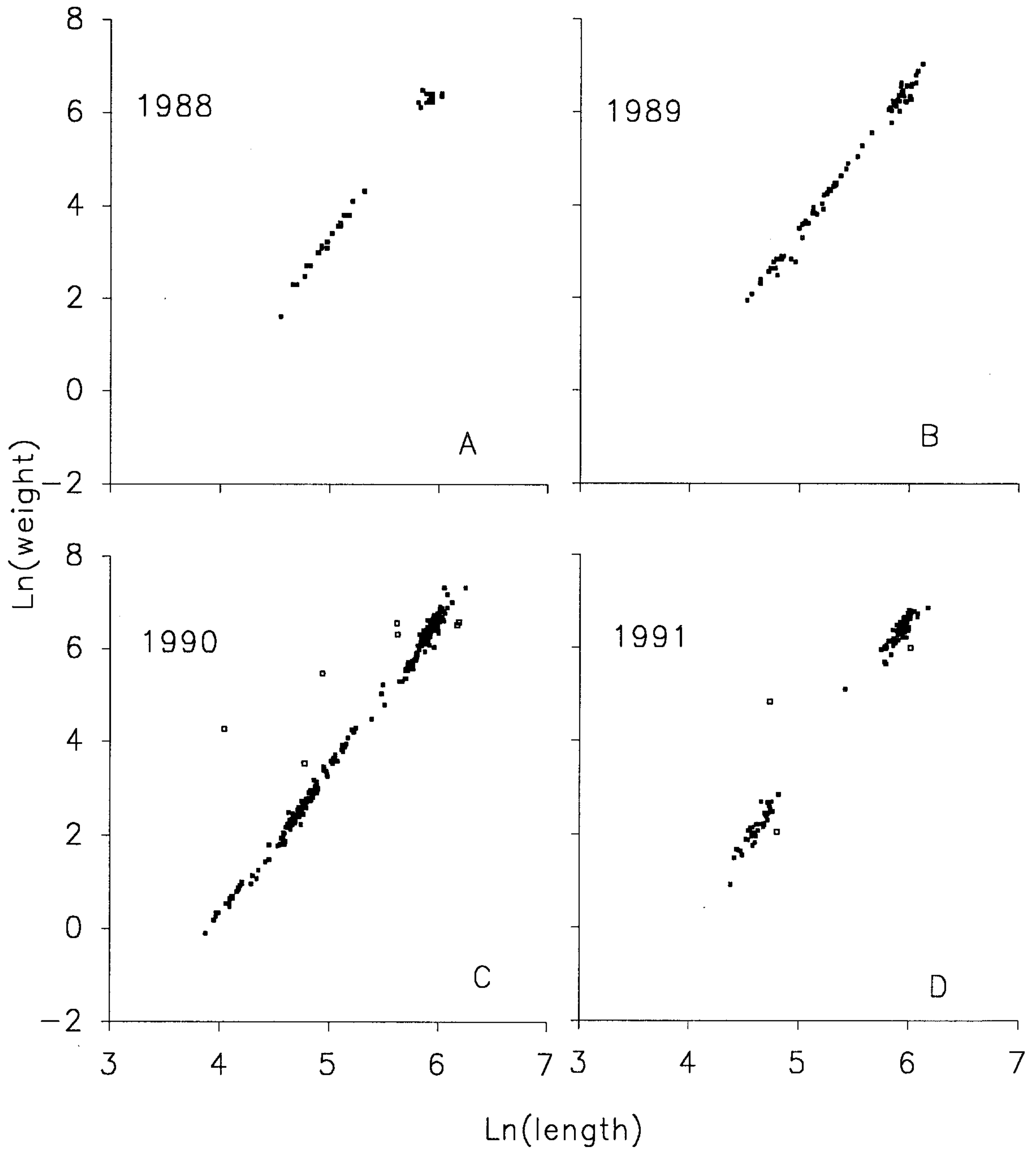

FIGURE 3.64.— Log-transformed Arctic cisco weight-length data (□ = outliers) collected during July in all areas for comparisons among years.

TABLE 3.31.— Annual condition comparisons for Arctic cisco collected after August 27 for all sampling areas combined and the Kaktovik/Jago Lagoon separately. Asterisks (*) indicate significant changes in condition.

Group	N	Slopes: b(SE)	Slopes: P-values	Intercepts: $\log_e a$(SE)	Intercepts: P-values	r^2	Pairwise results
All Areas							
1988	35	3.45 (0.07)		-14.09 (0.35)		0.99	
1989	139	3.13 (0.08)		-12.21 (0.43)		0.91	
1990	156	3.12 (0.04)		-12.19 (0.18)		0.97	
1991	250	3.19 (0.03)		-12.53 (0.14)		0.98	
			$P = 0.049$		$P = 0.0001$		
	Without outliers		$P = 0.0001$		$P = 0.0001$		
Beaufort Lagoon							
1990	51	3.09 (0.10)		-12.06 (0.47)		0.95	
1991	126	3.19 (0.03)		-12.50 (0.16)		0.99	
			$P = 0.26$		$P = 0.817$		
	Without outliers		$P = 0.0005$		$P = 0.42$		
Kaktovik and Jago lagoons							
1989	39	2.72 (0.24)		-10.36 (1.21)		0.77	
1990	68	3.16 (0.04)		-12.38 (0.18)		0.99	
1991	41	3.18 (0.03)		-12.49 (0.19)		0.99	
			$P = 0.01$		$P = 0.07$		
	Without outliers		$P = 0.77$		$P = 0.0002$	*	
Simpson Cove							
1989	100	3.21 (0.02)		-12.53 (0.13)		0.99	A
1990	37	3.08 (0.04)		-11.97 (0.16)		0.99	A
1991	82	3.23 (0.07)		-12.80 (0.37)		0.97	B
			$P = 0.263$		$P = 0.004$	*	
	Without outliers		$P = 0.0001$		$P = 0.0001$		

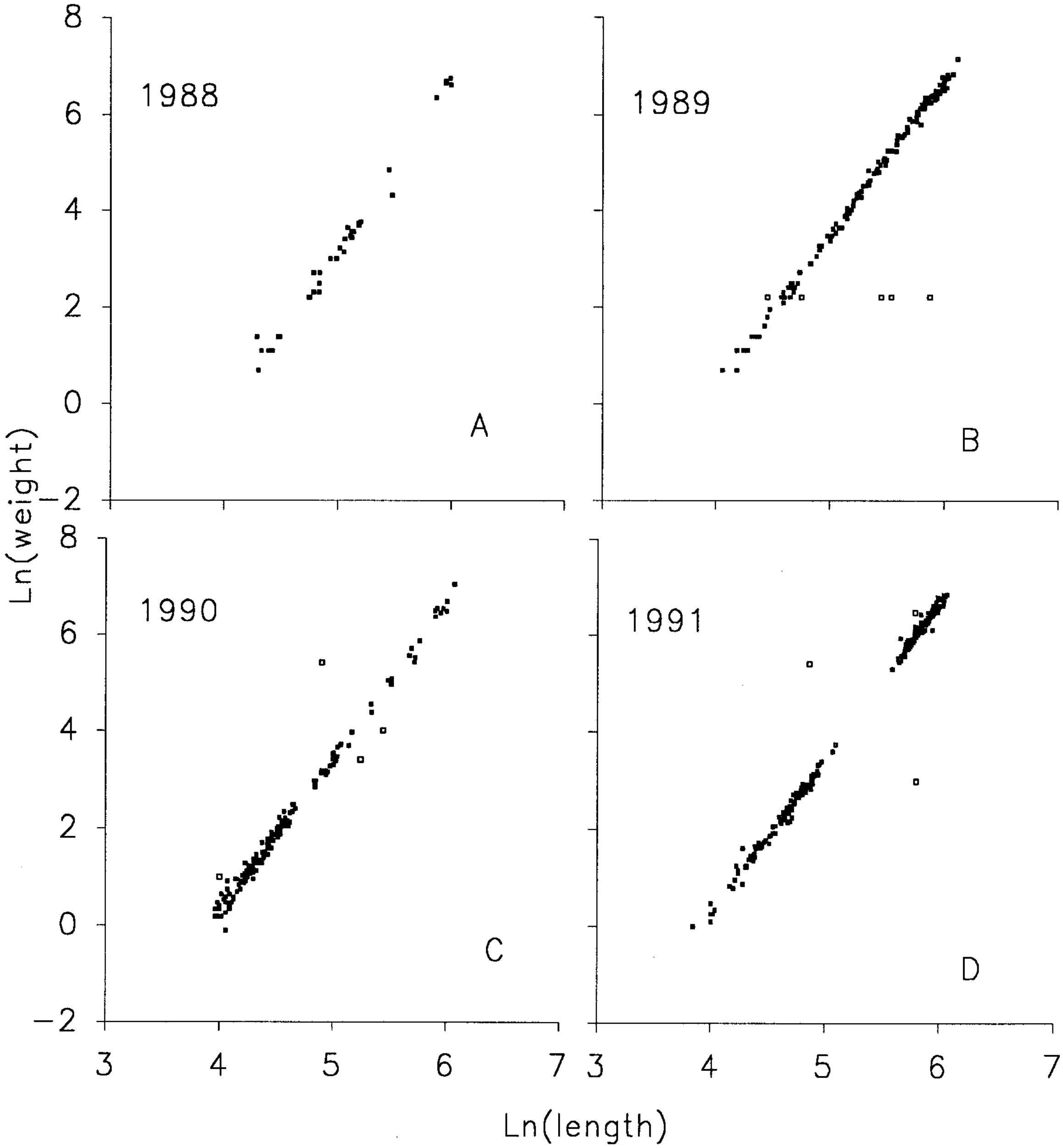

FIGURE 3.65.— Log-transformed Arctic cisco weight-length data (□ = outlier) collected after August 27 in all areas for comparison among-years.

TABLE 3.32.— Mean length at age (SE) and ranges for Arctic cisco collected during July, all years and areas pooled.

Age	*N*	$\bar{x}$(SE)	Range
0	64	58(1)	35-81
1	137	108(1)	83-125
2	112	145(1)	126-172
3	41	190(2)	174-207
4	17	238(3)	216-262
5	4	318(12)	286-341
6	8	339(4)	328-361
7	20	362(6)	325-425
8	26	378(5)	341-435
9	38	382(3)	343-429
10	23	388(7)	283-445
11	9	403(8)	377-442
12	1	412(--)	--
13	2	442(14)	428-455
	N = 502	$\bar{x}$ = 191	

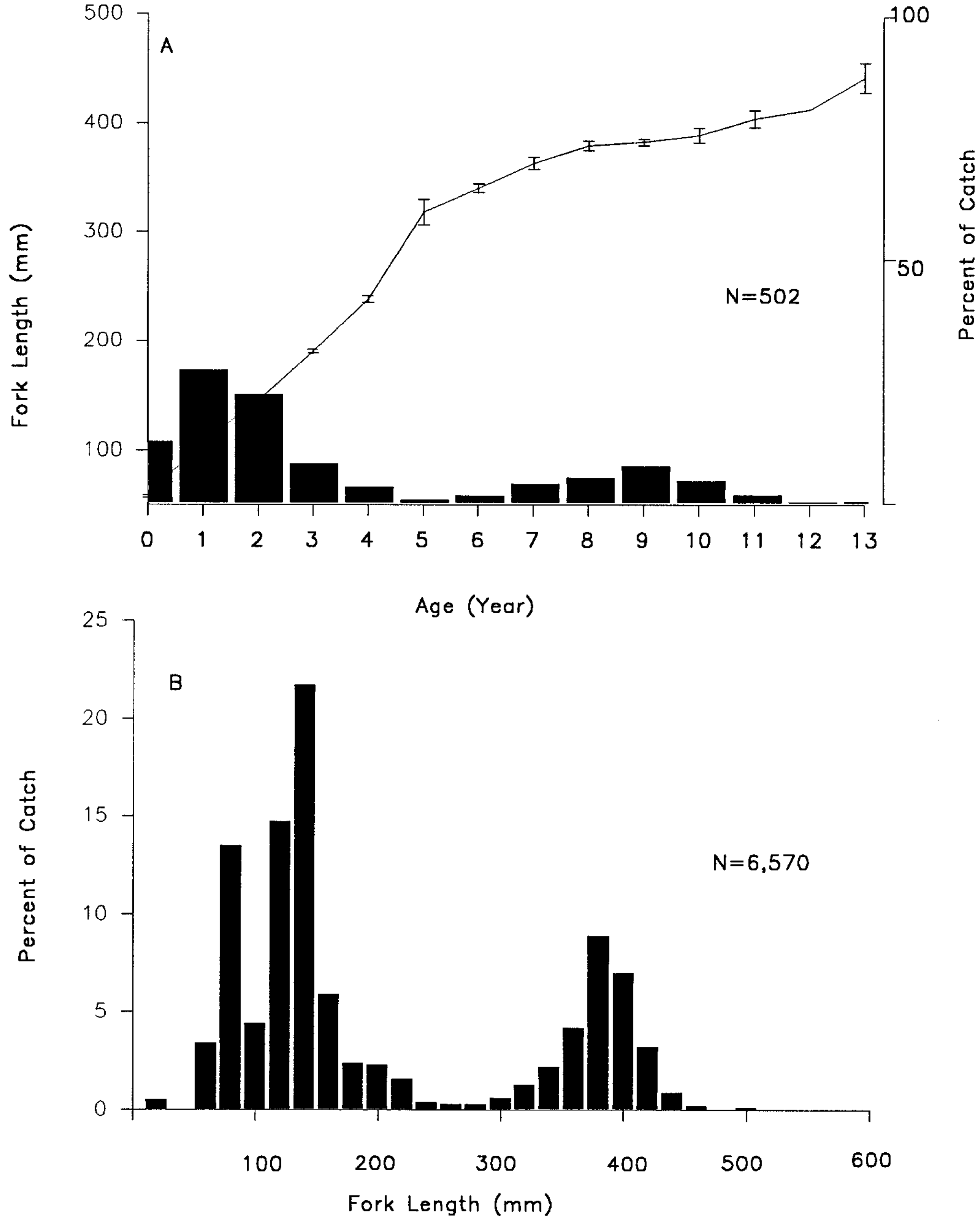

FIGURE 3.66.– Mean length at age (±SE), age frequencies (A), and length frequencies (10 mm intervals, B) for Arctic cisco collected from standard fyke nets during July, years and areas pooled.

TABLE 3.33.– Mean lengths at age (SE) for Arctic cisco collected during July, 1988-91. Similar letters within a row represent no significant difference among those means.

Age	Simpson Cove			Kaktovik Lagoon			Jago Lagoon			Beaufort Lagoon		
	N	$\bar{x}$(SE)		N	$\bar{x}$(SE)		N	$\bar{x}$(SE)		N	$\bar{x}$(SE)	
0	0	--		0	--		45	55(1)		19	64(1)	A
1	38	113(1)	A	11	107(2)	A	35	109(2)	A	53	104(2)	A
2	36	144(2)	A	13	150 (4)	A	30	146(2)	A	33	144(3)	A
3	22	193(2)	A	1	189(--)		4	190(5)	A	14	186(3)	A
4	4	228(5)	B	0	--		5	249(4)	A	8	235(5)	A
5	3	329(8)		0	--		1	286(--)		0	--	
6	8	340(4)		0	--		0	--		0	--	
7	11	371(9)	A	1	369(--)		5	344(5)	A	3	360(5)	A
8	14	378(7)	A	1	380(--)		6	381(9)	A	5	378(9)	A
9	17	381(5)	A	5	395(10)	A	10	380(5)	A	6	377(4)	A
10	11	384(12)	A	1	357(--)		2	385(10)	A	9	399(7)	A
11	3	407(18)	A	2	408(2)	A	0	--		3	387(8)	A
12	0	--		1	412(--)		1	436(--)		0	--	
13	2	441(14)		0	--		0	--		0	--	

TABLE 3.34.– Mean lengths at age (SE) for Arctic cisco collected during July, areas pooled. Similar letters within a row represent no significant difference among those means.

	1988			1989			1990			1991		
Age	N	$\bar{x}$(SE)		N	$\bar{x}$(SE)		N	$\bar{x}$(SE)		N	$\bar{x}$(SE)	
0	1	65(--)		0	--		63	58(1)		0	--	
1	8	109(5)	**AB**	12	112(3)	**A**	99	109(1)	**A**	18	99(2)	**B**
2	13	148(4)	**AB**	13	152(4)	**A**	85	144(1)	**AB**	1	127(--)	**B**
3	4	187(6)	**A**	18	195(2)	**A**	19	187(2)	**A**	0	--	
4	0	--		5	237(8)	**A**	12	238(3)	**A**	0	--	
5	0	--		1	286(--)		0	--		3	329(8)	
6	0	--		0	--		0	--		8	340(4)	
7	0	--		6	348(6)	**A**	0	--		14	369(7)	**A**
8	6	374(11)	**A**	8	369(5)	**A**	0	--		12	388(7)	**A**
9	5	381(5)	**A**	20	380(5)	**A**	0	--		13	386(5)	**A**
10	0	--		10	382(6)	**A**	0	--		13	393(11)	**A**
11	0	--		4	423(9)	**A**	0	--		5	388(5)	**A**
12	0	--		1	412(--)		0	--		0	--	
13	0	--		2	441(14)		0	--		0	--	

at age-1, the small sample size of one in 1991 makes this comparison questionable.

Length frequency distributions for the study area from 1988-91 (Figure 3.66B) indicated a strong bimodality. The first length mode occurred between 100 and 200 mm, the second around 380 mm. The apparent lack of samples between 200 and 300 mm FL was also indicated in the sampling season length frequencies stratified by area and year (see ***Length Frequency*** above), and is probably reflected in the small percentages Arctic cisco from ages 5 to 7 (Figure 3.66A). By area, the length and age frequencies were similar to the pooled frequencies. Except for Simpson Cove, the July length frequencies indicated a bimodal pattern, and the age frequencies indicated a lack of fish between ages 5 and 7 (Figure 3.67). In Kaktovik Lagoon, there were no Arctic cisco caught at ages 4-6.

By year, the length frequencies were similar to those in the area comparisons and in the overall length frequencies for July (Figure 3.68). The age frequencies also showed relatively strong modes at early ages (0-3) and at later ages (7-10) except for 1990. During that year, only Arctic cisco $\leq$ 250 mm FL were collected.

Movements

Between 1988 and 1991, a total of 5,734 Arctic cisco were marked, e.g. dye marked, ink marked, or fin clipped (Table 3.35). Arctic cisco < 250 mm FL were marked during 1988-89 and those fish < 300 mm FL were marked in 1990-91. By 1992, 70 Arctic cisco had been recaptured. Less than 12% of the recaptured Arctic cisco were found in sampling areas other than where they were initially captured and marked. These fish displayed movement between Camden Bay and two other sampling areas (Pokok Bay and the Kaktovik/Jago Lagoon complex), and between Beaufort Lagoon and the Kaktovik/Jago Lagoon complex. In addition, the movement of four Arctic cisco dye marked by LGL Alaska Research Associates, Inc. (LGL), at Prudhoe Bay in 1989 was documented. These fish were recaptured to the east of Prudhoe Bay: three in Camden Bay and one in Jago Lagoon.

A total of 919 Arctic cisco were tagged and released in the study area (Table 3.36). Three Arctic cisco were recaptured less than five kilometers from their respective sampling areas (Appendix B). Coastal movements of 16 recaptured Arctic cisco were also documented showing both eastern and western movement. Seven Arctic cisco (two from previous years) tagged by LGL, one from Harrison Bay, and six from the Prudhoe Bay area travelled east, and were recaptured in the study area. Three of the seven were at large for more than one season. The remaining four were recaptured from 13 to 25 days after tagging. One Arctic cisco tagged in Oruktalik Lagoon and eight tagged in Camden Bay moved west. The fish tagged in Oruktalik Lagoon was recaptured in Camden Bay three years after tagging. The remaining eight were recaptured in the Colville River during the fall commercial fishing season.

Environmental Influences on CPUE: Arctic cisco $\leq$ 200 mm FL

Simpson Cove.— Small Arctic cisco were present in Simpson Cove in varying densities throughout the 1989 and 1990 sampling seasons, with little apparent

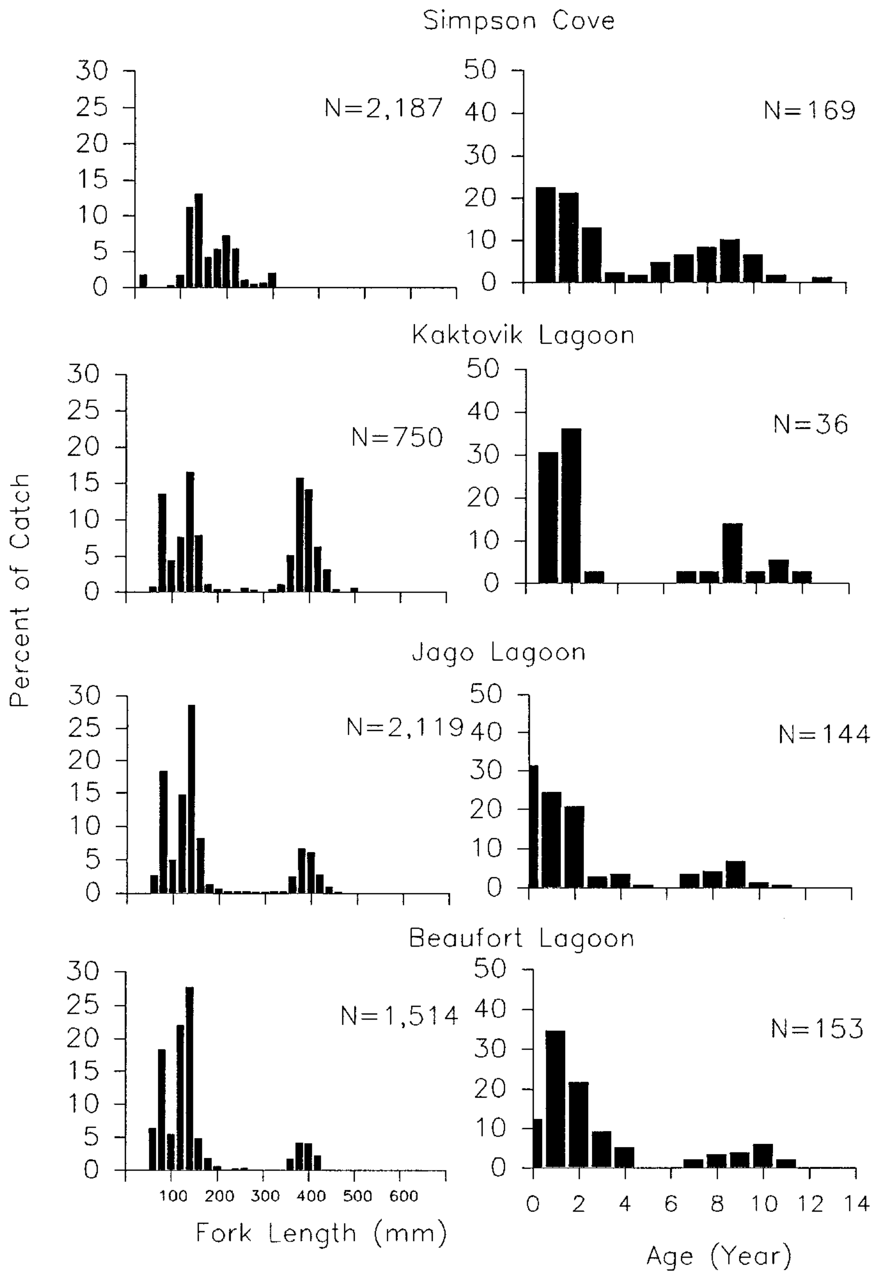

FIGURE 3.67.— Length frequencies (20 mm intervals) for standard fyke net catches and age frequencies for Arctic cisco collected during July, with years pooled.

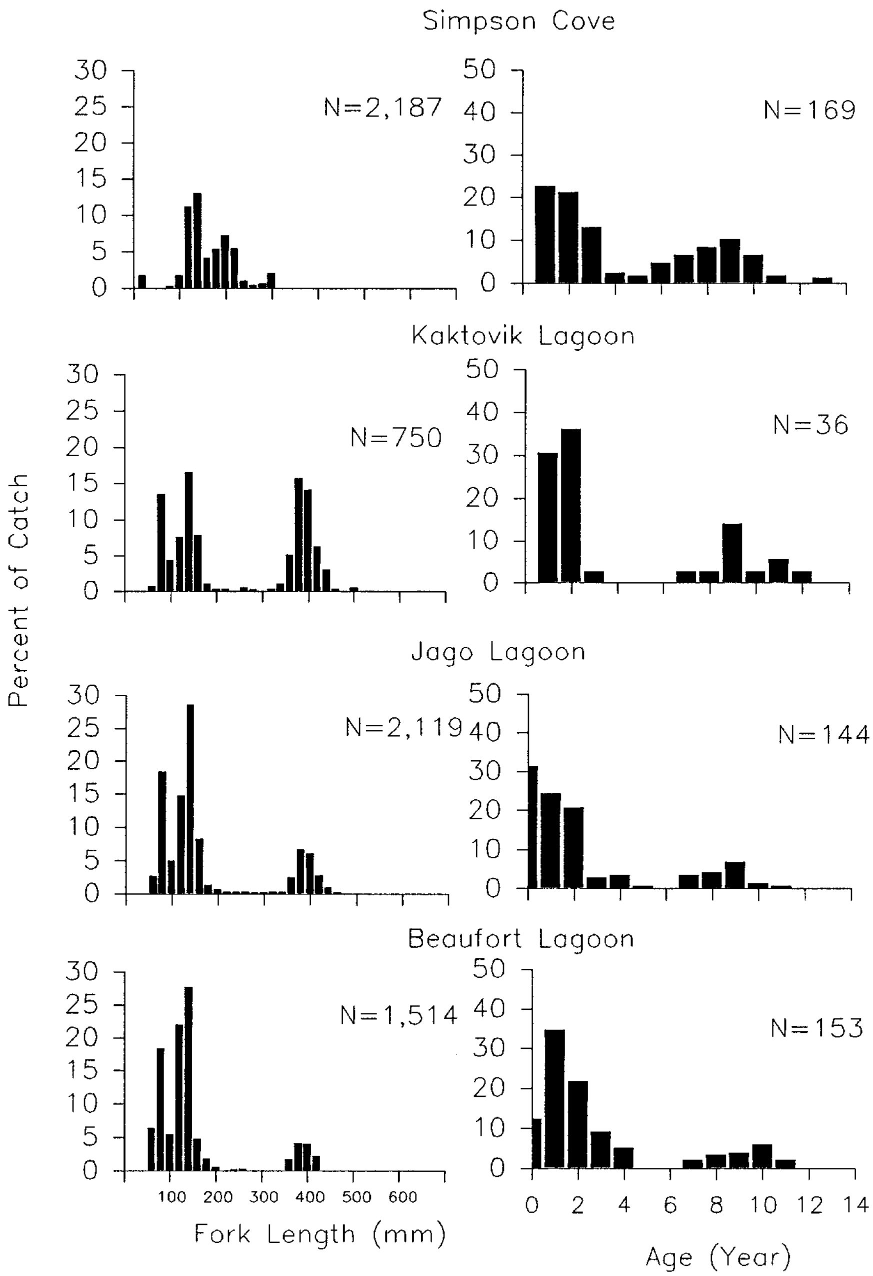

FIGURE 3.68.— Length frequencies (20 mm intervals) for standard fyke net catches and age frequencies for Arctic cisco collected during July, with years pooled.

TABLE 3.35.— Number of Arctic cisco marked (N) and recaptured by location in Arctic Refuge coastal waters, summer 1988-91.

		Recapture area			
Marking area	N	Camden Bay	Kaktovik and Jago lagoons	Beaufort Lagoon	Pokok Bay
Camden Bay	1444	7	4	0	1
Kaktovik/Jago	2701	1	21	0	0
Beaufort Lagoon	685	0	1	2	0
Pokok Bay	904	1	0	0	32

TABLE 3.36.— Number of Arctic cisco tagged (N) and recaptured by location in Arctic Refuge coastal waters, 1988-91.

		Recapture area				
Tagging area	N	Camden Bay	Kaktovik Lagoon	Jago Lagoon	Beaufort Lagoon	Pokok Bay
Camden Bay	359	0	0	0	0	0
Kaktovik Lagoon	165	0	0	0	0	0
Jago Lagoon	133	0	0	0	0	0
Beaufort Lagoon	138	0	0	0	0	0
Pokok Bay	120	0	0	0	0	0

correlation between daily catch rates and environmental variables (Figure 3.69). Stepwise regression revealed no strong linear dependencies between CPUE and temperature, salinity, or wind vector elements for individual stations or pooled station data from 1989 and 1990 (Tables 3.37-3.38).

Relatively few small Arctic cisco were caught in Simpson Cove during the summer of 1991, particularly during July and early August. Small numbers of small Arctic cisco were captured after the first week of August, coincident with a marked increase in salinities. Pearson correlation coefficients (Figure 3.69) and stepwise regression results also suggested a strong positive association between CPUE and salinity ($R^2 \geq 0.49$; Tables 3.37-3.38).

Kaktovik Lagoon.– Daily catch rates for small Arctic cisco were negligible in Kaktovik Lagoon in 1989 until the last week of August and early September, when salinities exceeded 15 ppt and temperatures were below 10°C. This observed small rise in late-season daily catch rates was directly correlated with salinity and inversely related to temperature (Figure 3.70). Increasing salinity and decreasing temperature were also selected by stepwise regression as being primarily associated with CPUE for both net stations KL05 and KL10 (Table 3.37) and for the entire sampling area (Table 3.38).

Daily catch rates during 1990 were highly variable in Kaktovik Lagoon, and Pearson correlations between CPUE and environmental variables were mostly weak ($|r| \leq 0.32$). Three large, distinct pulses of small Arctic cisco apparently moved into Kaktovik Lagoon on July 31 - August 2, August 8-12, and September 5-11. Analyses of available data did not detect the occurrence of any consistent or unique environmental patterns during these periods. Similar equivocal results were apparent from the much reduced daily catch rates observed in 1991 (Figure 3.71). Daily catch rates did not exceed six fish per day in Kaktovik Lagoon during 1991, rendering any correlations with physical variables tenuous at best. While salinity was selected as the dominant explanatory value by stepwise regression, the associations were weak ($R^2 \leq 0.23$; Tables 3.37-3.38). The significant salinity effect was the result of the corresponding intraseasonal trends of increasing salinity and daily catch rates over time, and does not necessarily imply a cause and effect relationship.

Jago Lagoon.– In 1989, small Arctic cisco appeared in Jago Lagoon in mid-August, when temperatures were less than 10°C and salinities exceeded 10 ppt. High correlations existed between daily catch rates and temperature and salinity, particularly for net station JL12 (Figure 3.72). Similarly, stepwise regression detected a strong negative relationship between CPUE and temperature (Tables 3.37-3.38).

Small Arctic cisco were extremely abundant in Jago Lagoon during the summer of 1990: CPUE exceeded 7,000 fish/d on August 3. Analyses revealed few strong dependencies between CPUE and environmental variables, except for net station JL12, where daily catch rates were negatively associated with north and east wind components ($R^2 = 0.73$, Table 3.37). As in other sampling locations, however, large daily variability in CPUE over a short sampling season hindered detection of any consistent patterns. Daily catch rates in 1991 were small

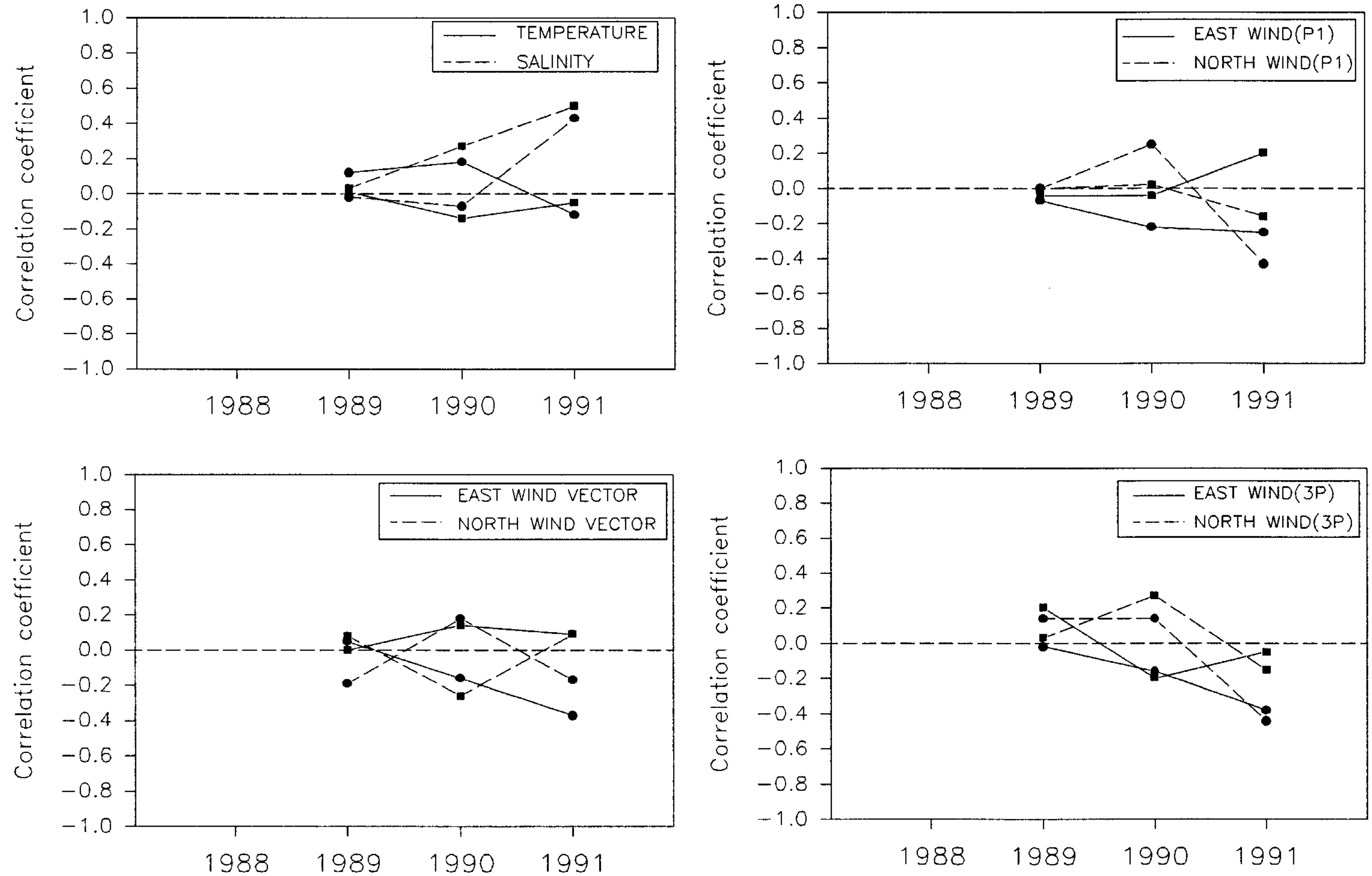

FIGURE 3.69.– Correlations between environmental variables and Arctic cisco (≤ 200 mm FL) CPUE from net stations SC01 (•) and SC04 (▪) (1989-91) in Simpson Cove. (1P=mean wind vector for previous day; 3P=mean wind vector over 3 previous days).

TABLE 3.37.— Environmental variables[a] influencing Arctic cisco (≤ 200 mm FL) CPUE (fish/d), followed by R^2 value of overall model. Parameter estimate is positive unless followed by "(-)". ("nv" = no eligible variables.)

Station	Year 1989	1990	1991
Simpson Cove			
SC01	nv	TEMP (0.18)	SAL TEMP EW(-) EW3P(-) (0.69)
SC04	nv	SAL NW3P (0.32)	SAL TEMP (0.49)
Kaktovik Lagoon			
KL05	TEMP(-) NW(-) SAL (0.42)	nv	SAL (0.23)
KL10	SAL NW(-) (0.48)	EW3P(-) (0.25)	nv
Jago Lagoon			
JL12	TEMP(-) SAL (0.72)	NW3P(-) EW1P(-) TEMP (0.73)	nv
JL14	TEMP(-) (0.43)	nv	EW1P NW (0.37)
Beaufort Lagoon			
BL02		SAL(-) NW(-) (0.52)	TEMP(-) NW1P(-) NW(-) (0.66)
BL04		NW1P(-) EW(-) (0.57)	NW1P(-) TEMP(-) SAL NW(-) (0.83)

[a] EW=mean east wind vector; EW1P=mean east wind vector for previous day; EW3P=mean of east wind vector over 3 previous days; NW=mean north wind vector; NW1P=mean north wind vector for previous day; NW3P=mean north wind vector over 3 previous days; SAL=salinity(ppt); TEMP=temperature(C).

TABLE 3.38.– Environmental variables[a] influencing Arctic cisco (≤ 200 mm FL) CPUE (pooled over stations). Coefficient of partial correlation (r^2_p) for each effect and overall R^2 shown as determined by stepwise selection procedure. ("nv" = no eligible variables.)

Year	Environmental variable	r^2_p	R^2
	Simpson Cove		
1989	nv		
1990	NW3P	0.06	0.06
1991	SAL	0.50	
	TEMP	0.14	
	EW3P	0.13	0.57
	Kaktovik Lagoon		
1989	SAL	0.39	
	NW	0.11	0.43
1990	EW	0.09	0.09
1991	SAL	0.20	
	TEMP	0.04	0.23
	Jago Lagoon		
1989	TEMP	0.54	
	SAL	0.08	0.56
1990	NW3P	0.19	0.19
1991	nv		
	Beaufort Lagoon		
1990	NW3P	0.11	
	EW3P	0.09	0.18
1991	NW1P	0.49	
	TEMP	0.47	
	NW	0.34	0.70

[a] EW=mean east wind vector; EW1P=mean east wind vector for previous day; EW3P=mean of east wind vector over 3 previous days; NW=mean north wind vector; NW1P=mean north wind vector for previous day; NW3P=mean north wind vector over 3 previous days; SAL=salinity(ppt); TEMP=temperature(C).

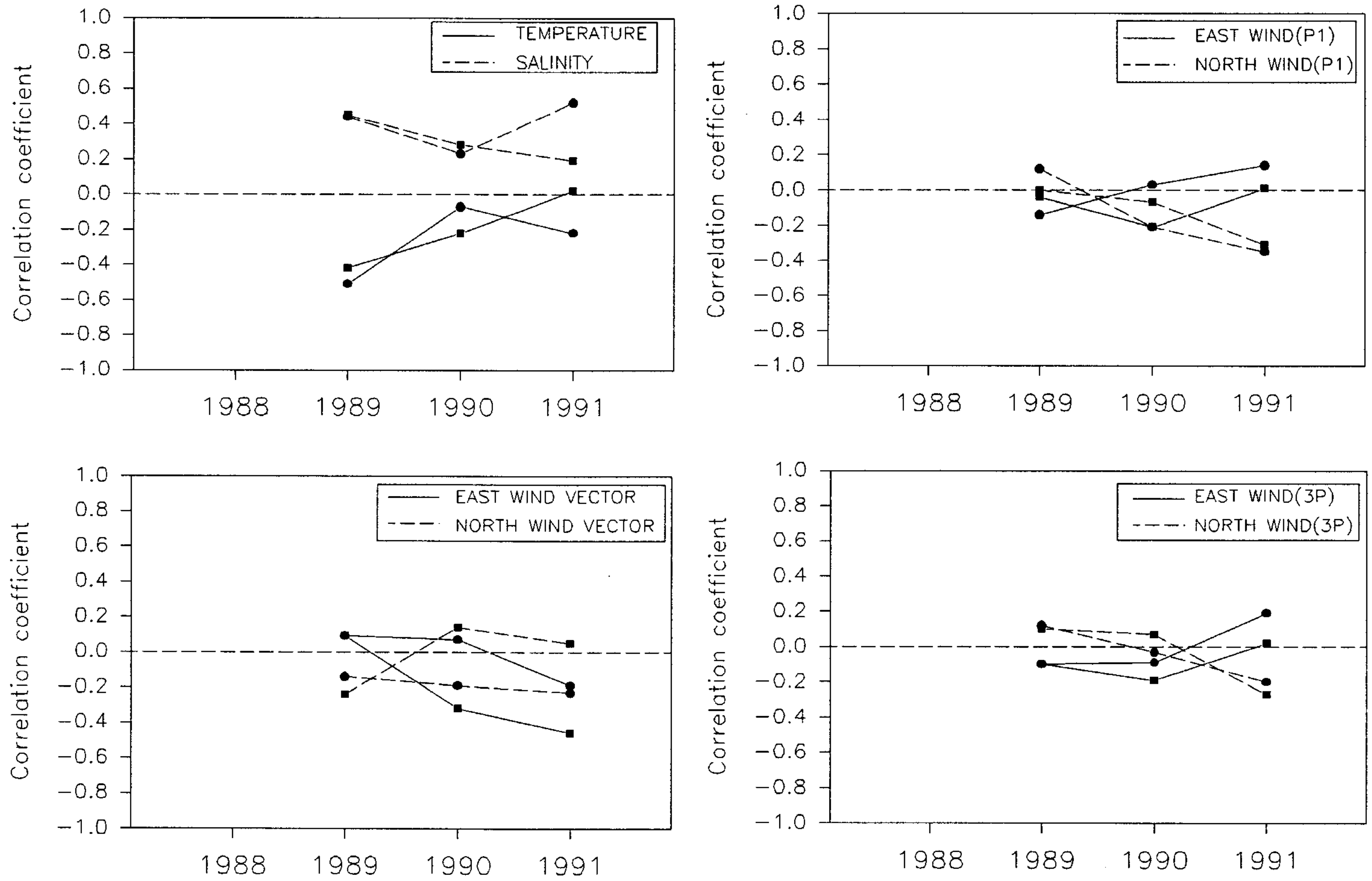

FIGURE 3.70.— Correlations between environmental variables and Arctic cisco ($\leq$ 200 mm FL) CPUE from net stations KL05 (•) and KL10 (▪) (1989-91) in Kaktovik Lagoon. (1P=mean wind vector for previous day; 3P=mean wind vector over 3 previous days).

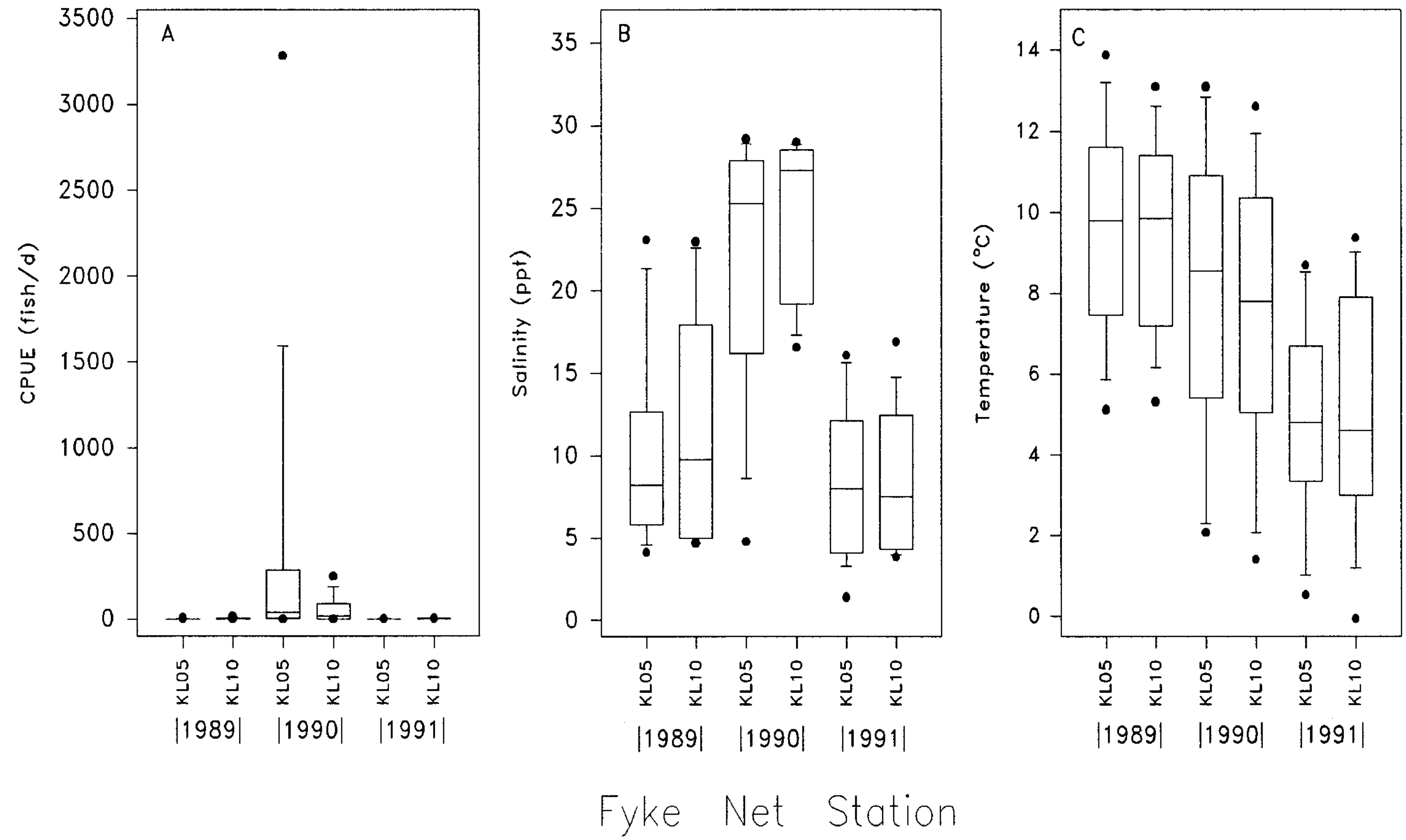

FIGURE 3.71.– Boxplots of (A) catch per unit effort for Arctic cisco $\leq$ 200 mm FL, (B) salinity, and (C) temperature for Kaktovik Lagoon net stations during 1989-91.

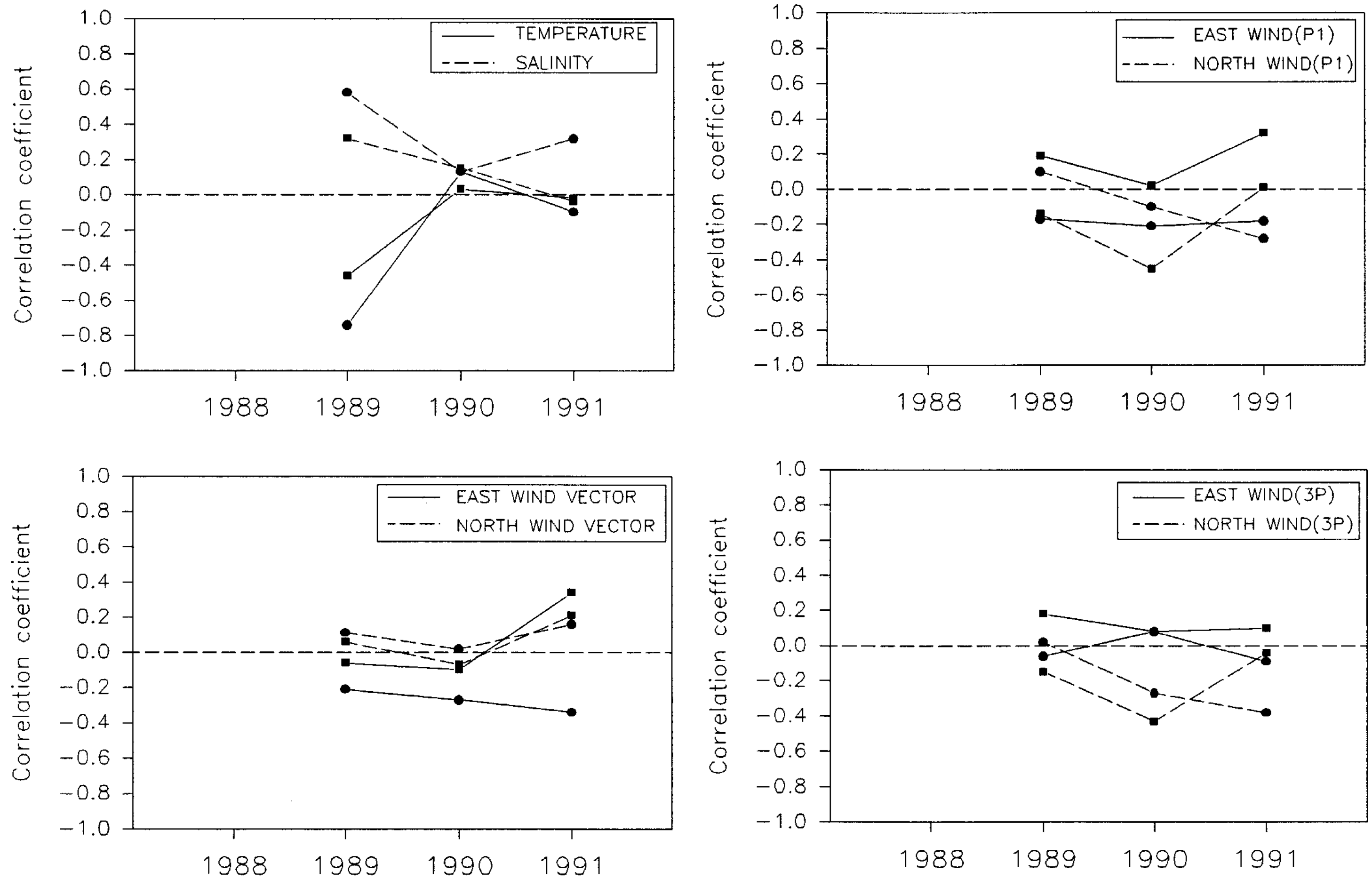

FIGURE 3.72.— Correlations between environmental variables and Arctic cisco ≤ 200 mm FL CPUE from net stations JL12 (•) and JL14 (▪) (1989-91) in Jago Lagoon. (1P=mean wind vector for previous day; 3P=mean wind vector over 3 previous days).

and correlations with hydrographic conditions were equivocal. Stepwise regression techniques were unsuccessful, with no significant variables available for the pooled area-wide data or for net station JL12. East and north wind components were associated with increased CPUE at net station JL14, although the relationship was weak (R^2 = 0.37, Table 3.37).

Beaufort Lagoon.— Similar to other sampling areas, small Arctic cisco were very abundant in Beaufort Lagoon during the summer of 1990. The majority of these fish were caught at the mainland shore net station BL02, although overall temperature and salinity parameters were similar for both net stations (Figure 3.73). Correlations of daily catch rates with both temperature and salinity varied in sign by net station in 1990 (Figure 3.74). Stepwise regression did not detect an association between CPUE and temperature or salinity for pooled net station data. A weak association with east and north wind components was instead indicated (R^2 - 0.18; Table 3.37). Station-specific modeling efforts were more successful. Negative associations between salinity and north winds for net station BL02, and north and east winds for net station BL04, resulted in relatively high R^2-values in the 1990 regression analyses (Table 3.37).

Small Arctic cisco appeared in Beaufort Lagoon in late July 1991 and remained present in variable numbers throughout the remainder of the sampling season. August was primarily dominated by shifting easterly and westerly winds, accompanied by low salinities and temperatures. North winds were more prevalent during the early part of the 1991 sampling season, previous to the influx of small Arctic cisco. Univariate Pearson correlation coefficients and stepwise multiple regression analyses of station-specific and pooled area data indicated CPUE was inversely related to both temperature and north wind components (Tables 3.37-3.38; Figure 3.74).

Environmental Influences on CPUE: Arctic Cisco > 200 mm FL

Simpson Cove.— No strong linear associations between eligible environmental variables and CPUE of large Arctic cisco were apparent in Simpson Cove throughout the study, particularly in 1989 and 1991. A moderate correlation (r = 0.35) between water temperature and daily catch rates at net station SC04 was present in 1990 (Figure 3.75) and was also reflected in the corresponding stepwise regression analysis (R^2 = 0.30; Table 3.39). Stepwise regression results for net station SC01 suggested an association between east wind components and daily catch rates in 1990 (R^2 = 0.36), although opposite signs attached to similar parameters confounded a parsimonious interpretation (Table 3.39). East wind components were also associated with the pooled Simpson Cove daily catch rates for 1990, although the model was only moderately successful (R^2 = 0.30; Table 3.40). Gross annual salinity trends varied greatly throughout the study, with 1990 salinities generally being much higher than 1989 or 1991 (Figure 3.76). A corresponding annual trend in CPUE was not apparent.

Kaktovik Lagoon.— Daily catch rates of large Arctic cisco at net station KL05 were highly negatively correlated with salinity in 1989 (r = -0.40; Figure 3.77). Stepwise regression also indicated an inverse association between salinity and 1989 CPUE at net station KL05 (R^2 = 0.28; Table 3.39). In general, however, few significant associations were detected in the

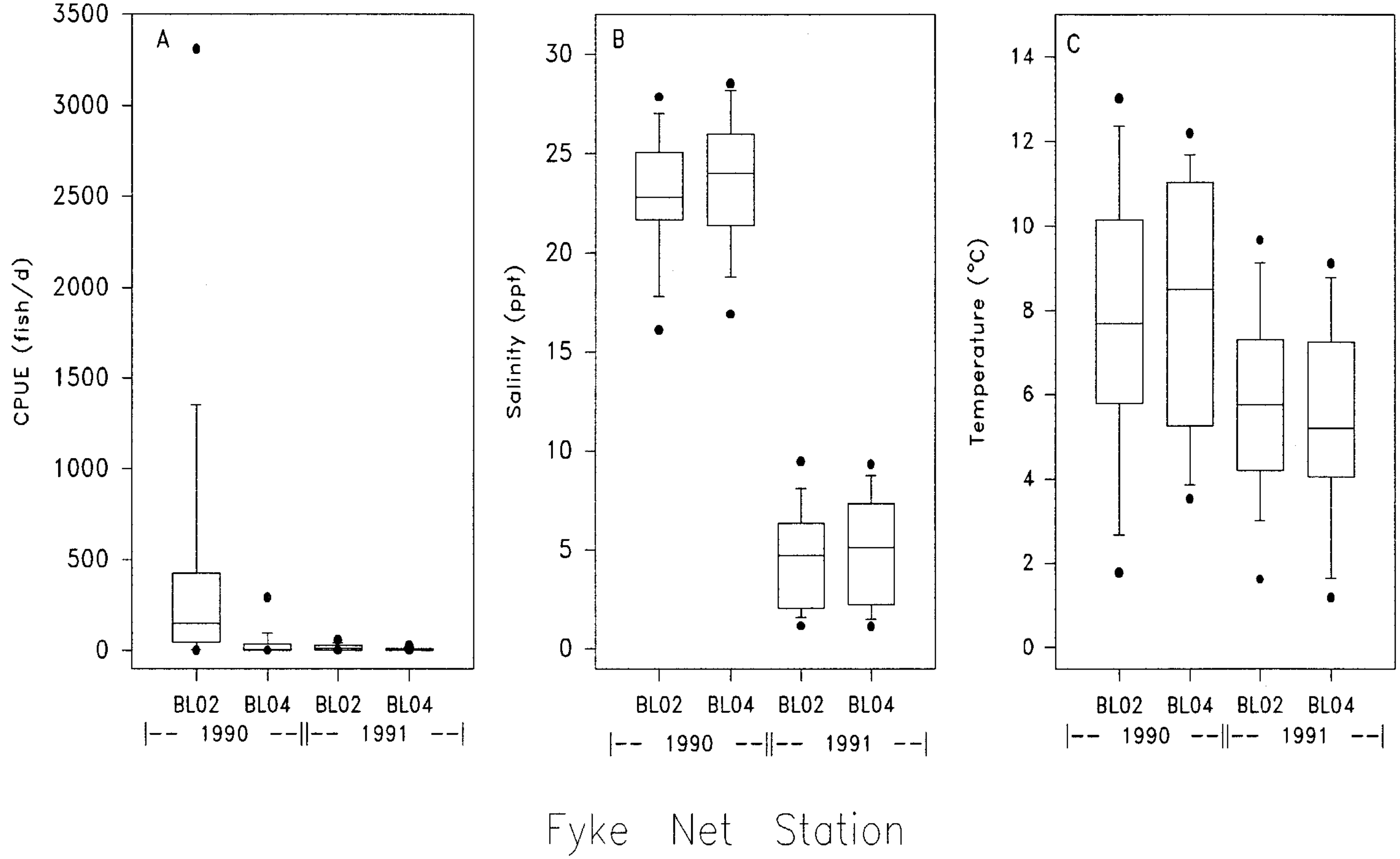

FIGURE 3.73.— Boxplots of (A) catch per unit effort for Arctic cisco ≤ 200 mm FL, (B) salinity, and (C) temperature (1990-91) for Beaufort Lagoon net stations.

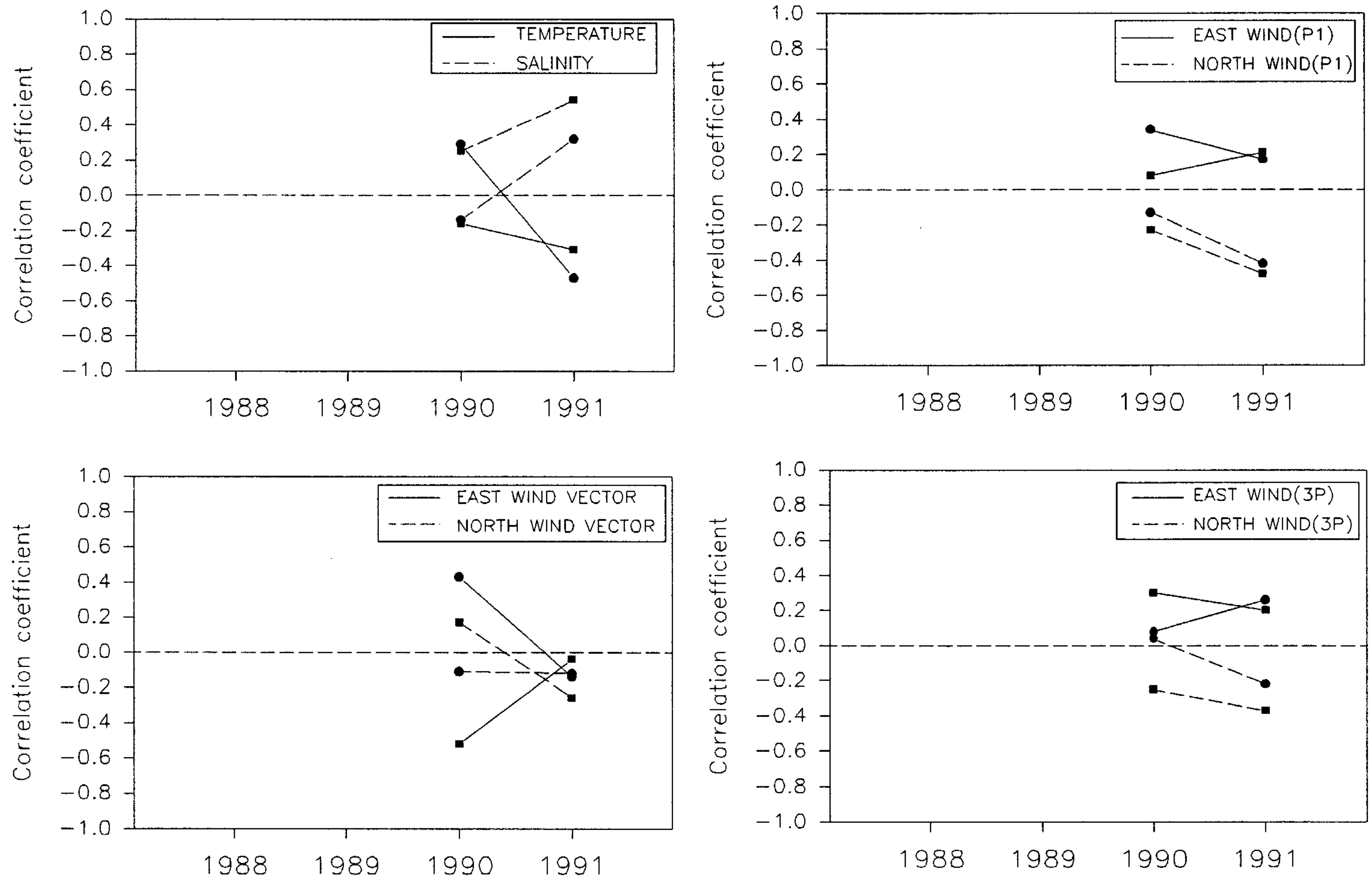

FIGURE 3.74.– Correlations between environmental variables and Arctic cisco ≤ 200 mm FL CPUE from net stations BL02 (•) and BL04 (▪) (1990-91) in Beaufort Lagoon. (1P=mean wind vector for previous day; 3P=mean wind vector over 3 previous days).

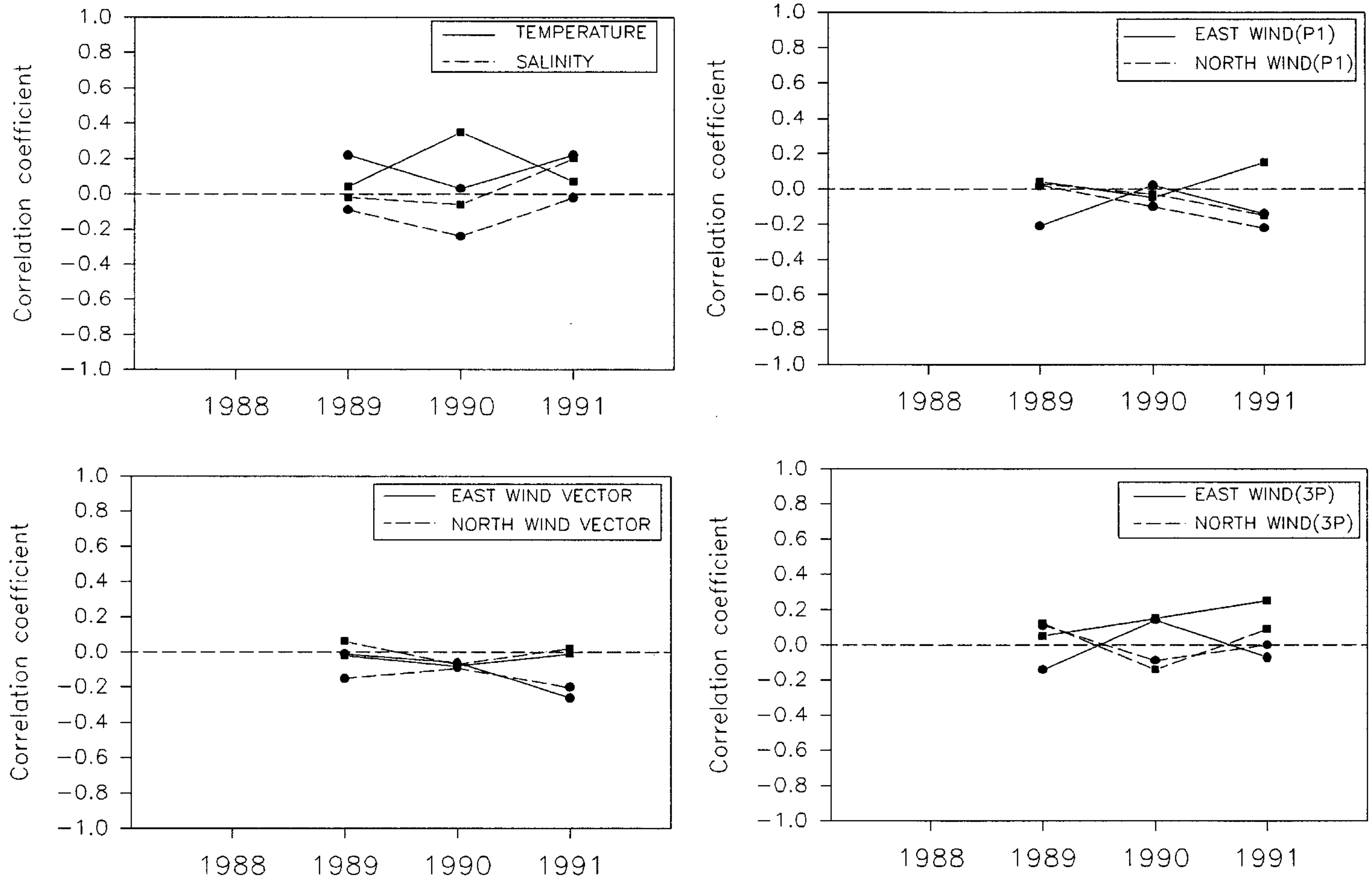

FIGURE 3.75.— Correlations between environmental variables and Arctic cisco > 200 mm FL CPUE from net stations SC01 (•) and SC04 (▪) (1989-91) in Simpson Cove. {1P=mean wind vector for previous day; 3P=mean wind vector over 3 previous days}.

TABLE 3.39.— Environmental variables[a] influencing Arctic cisco > 200 mm FL CPUE (fish/d), followed by R^2 value of overall model. Parameter estimate is positive unless followed by "(-)". ("nv" = no eligible variables.)

Station	Year 1989	1990	1991
Simpson Cove			
SC01	EW1P(-) (0.08)	EW1P(-) EW3P (0.36)	EW(-) (0.13)
SC04	nv	TEMP (0.30)	nv
Kaktovik Lagoon			
KL05	SAL(-) (0.28)	EW3P (0.26)	nv
KL10	nv	nv	nv
Jago Lagoon			
JL12	NW1P (0.10)	EW1P(-) (0.21)	nv
JL14	SAL(-) NW3P (0.37)	nv	nv
Beaufort Lagoon			
BL02		nv	EW3P(-) EW(-) (0.36)
BL04		SAL EW3P TEMP (0.40)	EW3P(-) NW3P(-) (0.41)

[a] EW=mean east wind vector; EW1P=mean east wind vector for previous day; EW3P=mean of east wind vector over 3 previous days; NW=mean north wind vector; NW1P=mean north wind vector for previous day; NW3P=mean north wind vector over 3 previous days; SAL=salinity(ppt); TEMP=temperature(C).

TABLE 3.40.— Environmental variables[a] influencing Arctic cisco > 200 mm FL CPUE (pooled over stations). Coefficient of partial correlation (r^2_p) for each effect and overall R^2 shown as determined by stepwise selection procedure. ("nv" = no eligible variables.)

Year	Environmental variable	r^2_p	R^2
	Simpson Cove		
1989	TEMP	0.06	0.06
1990	EW3P	0.28	
	EW1P	0.04	
	NW1P	0.01	0.30
1991	nv		
	Kaktovik Lagoon		
1989	NW	0.03	0.03
1990	TEMP	0.08	0.08
1991	nv		
	Jago Lagoon		
1989	SAL	0.07	
	NW1P	0.06	0.12
1990	nv		
1991	nv		
	Beaufort Lagoon		
1990	nv		
1991	EW3P	0.22	
	EW	0.14	0.31

[a] EW=mean east wind vector; EW1P=mean east wind vector for previous day; EW3P=mean of east wind vector over 3 previous days; NW=mean north wind vector; NW1P=mean north wind vector for previous day; NW3P=mean north wind vector over 3 previous days; SAL=salinity(ppt); TEMP=temperature(C).

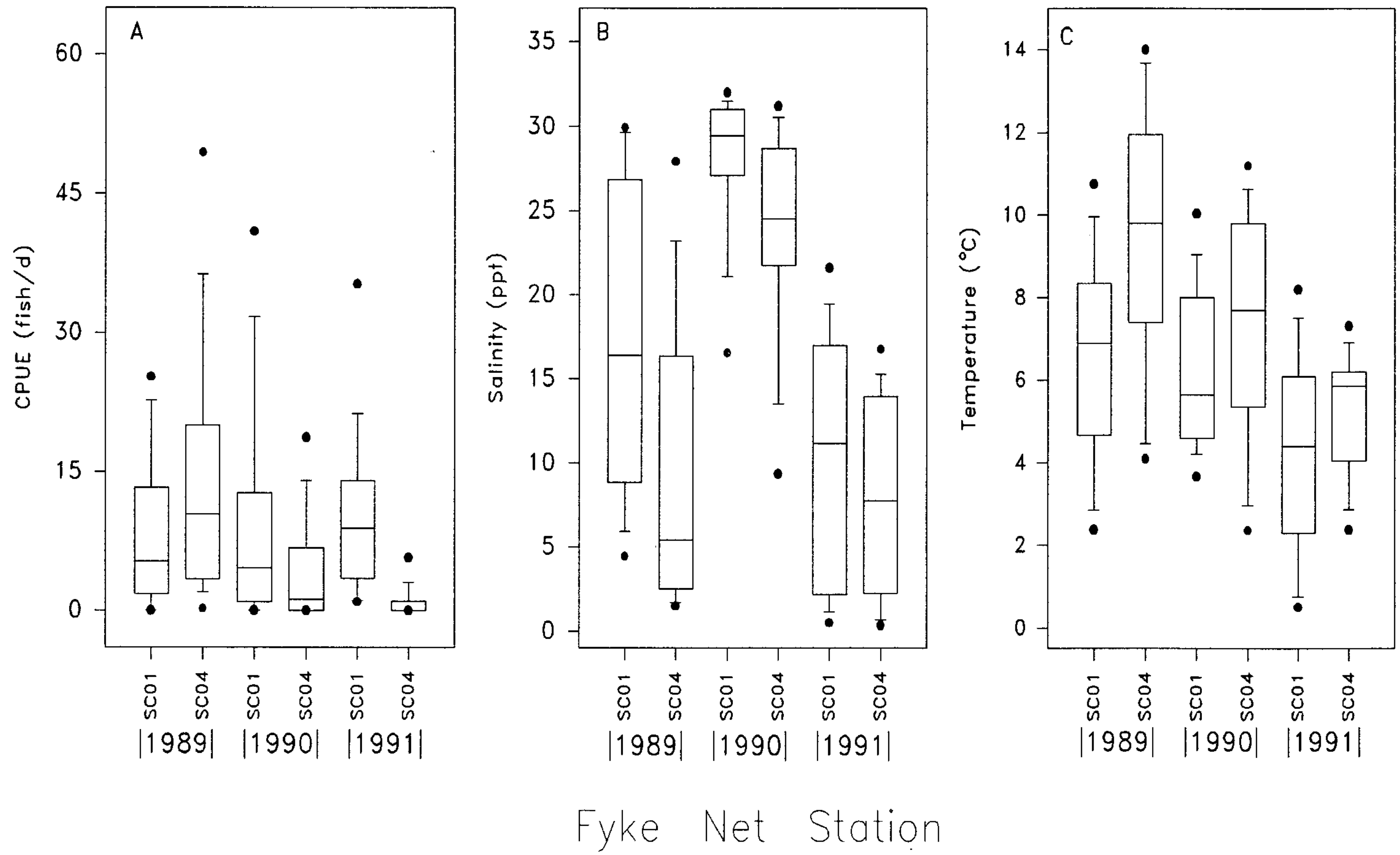

FIGURE 3.76.— Boxplots of (A) catch per unit effort for Arctic cisco > 200 mm FL, (B) salinity, and (C) temperature for Simpson Cove net stations during 1989-91.

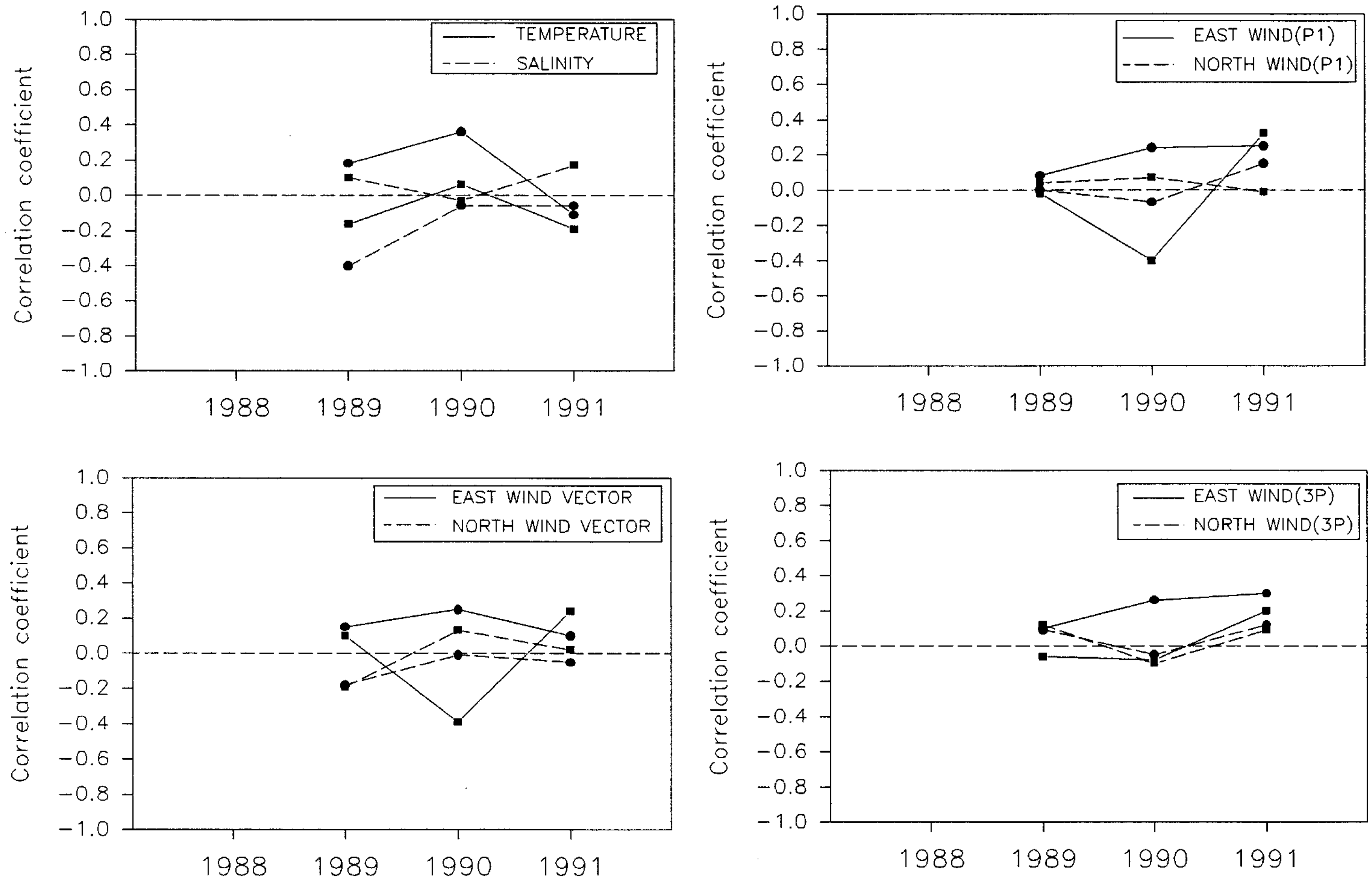

FIGURE 3.77.— Correlations between environmental variables and Arctic cisco > 200 mm FL CPUE from net stations KL05 (•) and KL10 (▪) (1989-91) in Kaktovik Lagoon. (1P=mean wind vector for previous day; 3P=mean wind vector over 3 previous days).

analyses of Kaktovik Lagoon daily catch rates and environmental data (Tables 3.39-3.40). No environmental variables were significantly associated with CPUE in most year×location analyses, and coefficients of determination were less than 0.28 in those analyses containing eligible variables.

Jago Lagoon.– Daily catch rates of large Arctic cisco at net station JL14 were negatively correlated (r = -0.49) with salinity in 1989 (Figure 3.78). Not unexpectedly, given the inverse relationship between temperature and salinity, net station JL14 daily catch rates were positively correlated with temperature (r = 0.39) during 1989. The univariate correlation results were reinforced by the multivariate stepwise regression results, where salinity was again selected as the variable primarily associated with CPUE at net station JL14 (R^2 = 0.37; Table 3.39). The remaining station-specific analyses did not detect any consistently strong patterns of relationships between daily catch rates and environmental conditions. The area-wide stepwise analyses again indicated an inverse association between salinity and daily catch rates in 1989 and was probably influenced by the correlation at net station JL14 mentioned above. The overall success of the model, however, was small (R^2 =0.12; Table 3.40). No environmental variables were significant in the 1990 and 1991 area-wide analyses.

Beaufort Lagoon.– Daily catch rates of large Arctic cisco in Beaufort Lagoon were low in August and September of 1990. This was particularly true at net station BL02, where large Arctic cisco were present in only one sample taken after July 26. While more fish were caught at net station BL04, CPUE generally decreased throughout the 1990 season as water temperatures decreased and salinity increased. Although some correlations between daily catch rates and environmental conditions were high for the 1990 data (Figure 3.79), the high frequency of zero daily catch rates caution against any strong inferences resulting from the 1990 analyses.

When compared to 1990, large Arctic cisco were more abundant in Beaufort Lagoon in 1991 when overall salinities were much lower (Figure 3.80). Pearson correlations and stepwise regression results suggest that CPUE was strongly inversely associated with east wind components (i.e. directly related to westerly winds) for both net stations within Beaufort Lagoon during 1991 (Figure 3.79; Table 3.39). East wind components were similarly significant in the area-wide analysis (R^2 = 0.31; Table 3.40).

Discussion

Relative Abundance and Distribution: Arctic Cisco ≤ 200 mm FL

Two-way ANOVA.– Our results indicate that year-to-year variation in daily catch rates of small Arctic cisco (≤ 200 mm FL) was greater than was the variation in spatial distribution along the Arctic Refuge coast during the study period. Large year-to-year variation in abundance of young Arctic cisco has been previously documented for the Beaufort Sea coast (Fechhelm and Fissel 1988; Fechhelm and Griffiths 1990; Schmidt et al. 1991). This annual variation is hypothesized to be partially a function of meteorologic events,

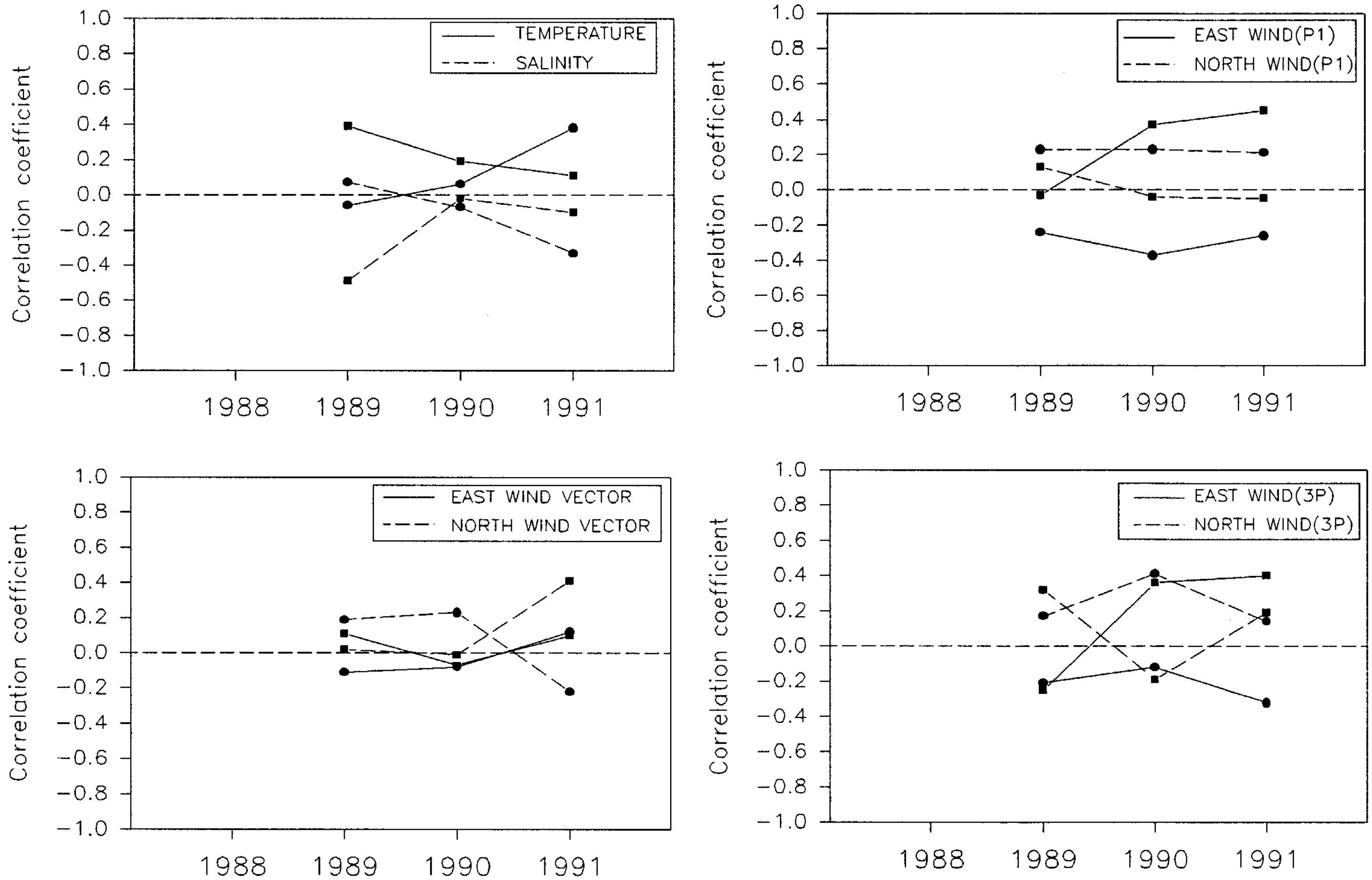

FIGURE 3.78.— Correlations between environmental variables and Arctic cisco > 200 mm FL CPUE from net stations JL12 (•) and JL14 (▪) (1989-91) in Jago Lagoon. (1P=mean wind vector for previous day; 3P=mean wind vector over 3 previous days).

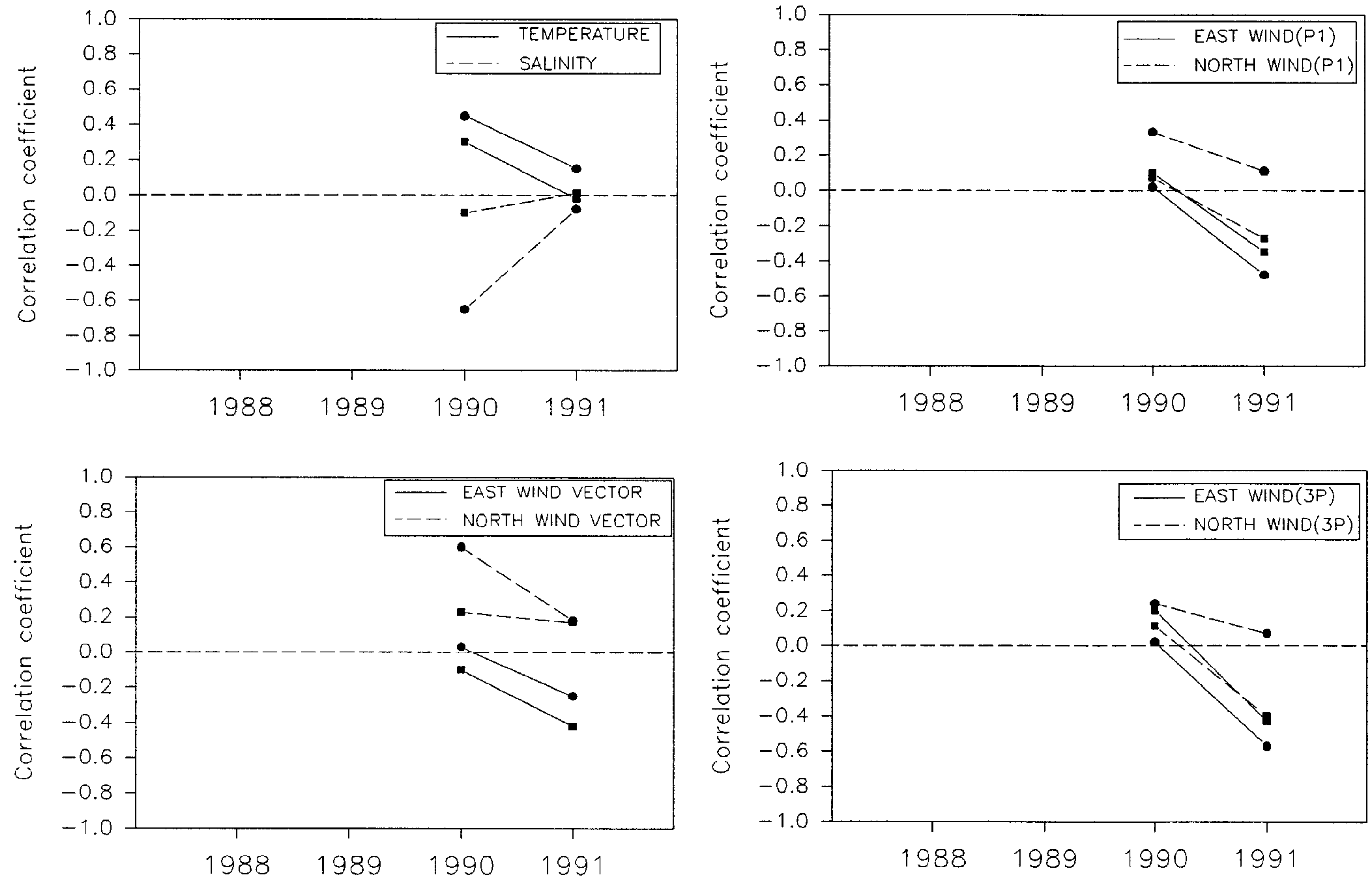

FIGURE 3.79.– Correlations between environmental variables and Arctic cisco > 200 mm FL CPUE from net stations BL02 (•) and BL04 (▪) (1990-91) in Beaufort Lagoon. {1P=mean wind vector for previous day; 3P=mean wind vector over 3 previous days}.

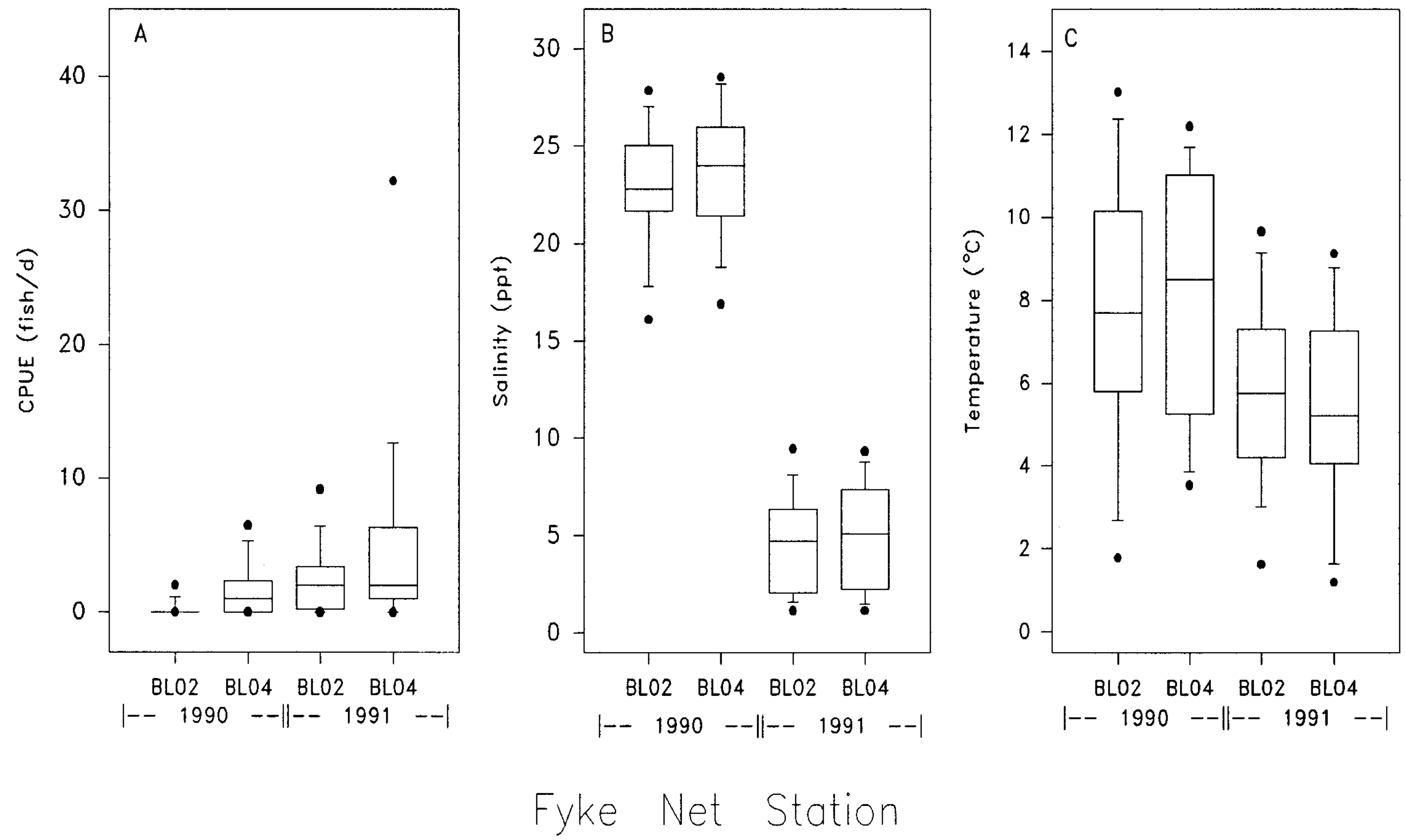

FIGURE 3.80.— Boxplots of (A) 1990-91 catch per unit effort for Arctic cisco > 200 mm FL, (B) salinity, and (C) temperature (1989-91) for Beaufort Lagoon net stations.

particularly the prevalence of easterly winds and their influence on Arctic cisco recruitment to Alaskan waters from Canada's Mackenzie River (Fechhelm and Griffiths 1990). Significantly higher daily catch rates occurred during the year (1990) with the most persistent easterly winds. This evidence is consistent with the hypothesis that recruitment of small Arctic cisco to the Alaskan coast is wind-aided (Fechhelm and Fissel 1988; LGL 1990; Schmidt et al. 1991). Large year-to-year variation may be expected when the parent stock spawns outside the Arctic Refuge coastal system and recruitment of individuals to Arctic Refuge waters is at least partially dependent on environmental conditions. This large annual variability suggests that long-term monitoring programs are needed to interpret variable CPUE patterns as a function of environmental conditions or development-related perturbations. Annual abundance cycles of small Arctic cisco may largely influence spatial distribution along the Alaskan coast and should be considered in future population assessments.

Spatial differences.— Large numbers of small Arctic cisco, particularly those $\leq$ 100 mm FL, have been observed to leave the Mackenzie River region and move westward along the Beaufort Sea coast to the Colville River (Gallaway et al. 1983; Cannon et al. 1987; Griffiths et al. 1991). Daily catch rates of > 1000 fish/d have been documented at coastal locations including Prudhoe Bay (Cannon et al. 1987), Kaktovik, Jago and Beaufort lagoons (Underwood et al. 1992). This movement has been hypothesized to be influenced by the direction of prevailing wind vectors during the sampling season (Fechhelm and Griffiths 1990).

The significantly higher daily catch rates observed for net stations BL02 (1990, 1991), BL04 (1991), and the Beaufort Lagoon sampling area (1990, 1991), than for other locations could be explained by this westward migration of small Arctic cisco. Beaufort Lagoon would be the first sampling area in the study area to be encountered by small Arctic cisco on their westward migration. The lower daily catch rates observed at some locations in Simpson Cove, Kaktovik and Jago lagoons could be evidence that these sites were not along the preferred migration route and/or that the wind-assisted movement, or lack of such, caused these sites to be missed.

Temporal differences.— The temporal differences observed in small Arctic cisco daily catch rates during the sampling season are consistent with those expected. Small Arctic cisco moving into and then out of areas on their westward migration to the Colville River would cause daily catch rates to increase, reach a maximum, and then drop off again during an open-water season. Patterns similar to this occurred at the Simpson Cove sampling area (1989-1991), Kaktovik Lagoon (1989), Jago Lagoon (1989, 1990), and Beaufort Lagoon (1991). Deviations in timing of arrival and in the residence time in a location could have been caused by prevailing environmental conditions.

Favorable conditions resulting in dispersal into nearshore areas prior to the beginning of sampling and departure after the conclusion of sampling could have caused the stable daily catch rates observed at net stations SC01, SC04, KL05, KL10, BL02 and BL04 in 1990. The presence of advantageous dispersal conditions is supported by the fact that 1990 daily catch rates were the highest of the years analyzed for net stations KL05, KL10, JL12, JL14, BL02 and for all sampling areas. This pattern was repeated within a time period for at least 3 of the 4 time periods at net stations KL05, JL12, JL14 and BL02.

The stable 1991 daily catch rates observed at net stations KL05, KL10, JL12, JL14, BL02 and BL04, could be an indication of low dispersal due to unfavorable migratory conditions. These unfavorable conditions are supported by the low daily catch rates observed during 1991, as compared to those in 1990, at net stations in Simpson Cove and Beaufort Lagoon and during parts of the sampling season in Kaktovik and Jago lagoons.

Future research on small Arctic cisco relative abundance and distribution will have to address several concerns. The experimental design should allow for the collection of CPUE data by size category. This information would assist in the determination of the contribution Arctic cisco $\leq$ 100 mm FL make to daily catch rates. It will be necessary to place net stations at sites to aid in the identification of migratory routes. Data from these locations will aid in ascertaining how the proximity of possible development sites will affect these locations. Also a long time series is essential to do meaningful comparisons. This information will provide clearer insights into the relative abundance and distribution of small Arctic cisco in the nearshore waters of the Arctic Refuge.

Relative Abundance and Distribution: Arctic Cisco > 200 mm FL

Two-way ANOVA.— Our results indicate that abundance of large Arctic cisco (> 200 mm FL), as indexed by CPUE, varied significantly among sampling areas within each year of the study. Contrary to our results for small Arctic cisco, overall variation from area to area appeared to be greater than that from year-to-year for large Arctic cisco. This appeared to result from the consistently high daily catch rates in Simpson Cove compared to other areas over the three years of available data. Larger sub-adult and mature nonspawning Arctic cisco are believed to overwinter primarily in the Colville River drainage, (Craig and Haldorson 1980; Cannon et al. 1987; Fechhelm et al. 1989). Smaller individuals may segregate and overwinter in the Sagavanirktok River drainage (Fechhelm et al. 1989). Both drainages are west of the study site and, assuming the foraging fish radiate outward along the coast from the overwintering areas, large Arctic cisco may be expected to occur in decreasing numbers in more easterly Arctic Refuge waters. This was the case during this study, although environmental factors may have equally influenced this longitudinal gradient in CPUE.

Spatial differences.— The prevalence of large Arctic cisco at the Simpson Cove net stations at the onset of sampling in 1989 and 1990 might be evidence of early summer dispersal from the Colville River. The higher daily catch rates observed for Simpson Cove and Beaufort Lagoon, than for Kaktovik and Jago lagoons, in 1991 could reflect dispersal patterns from the Colville and Mackenzie rivers, respectively. There are several factors which might have resulted in the lower daily catch rates observed at Kaktovik and Jago lagoons, 1989-91, and Beaufort Lagoon in 1990. These include poor feeding habitat, inadequate net locations to sample migrating fish, and/or unfavorable hydrographic conditions.

Temporal differences.— The declines in daily catch rates observed at some net and sampling area locations at the end of the sampling seasons might be indicative of large Arctic cisco having returned to overwintering riverine habitats. The stable daily catch rates observed at some locations during the sampling seasons could be caused by both favorable and unfavorable conditions. These favorable conditions, resulting in dispersal into nearshore areas prior to the beginning of sampling and return to overwintering habitat after the conclusion of sampling, could have caused the stable daily catch rates observed at net stations KL10 and JL12 in 1990. The stable 1991 daily catch rates observed at all net stations, excluding SC01, would then be an indication of low dispersal due to poor migratory conditions.

Among-year comparisons indicted few consistent patterns. One obvious trend indicated large Arctic cisco in Beaufort Lagoon were present in higher numbers during 1991 than during 1990. This abundance pattern suggests that dispersal from the Mackenzie River occurred in relatively higher numbers during 1991 than 1990, thus supporting the hypothesis of differing environmental conditions.

Future research on relative abundance and distribution of large Arctic cisco needs to address several issues: 1) sampling designs should incorporate catch information on both spawners and nonspawners; 2) sampling should be random by mobile fyke nets or the use of shallow water trawls; 3) a time series of data should cover an entire life cycle; and 4) sampling should occur at identified future development sites with known proximity to migratory routes. This information should provide insights and aid in describing the relative abundance and distribution of large Arctic cisco in the nearshore waters of the Arctic Refuge.

Length Frequency Distributions

Arctic cisco length frequency distributions were similar to those in other studies along the Beaufort Sea coast (Gallaway et al. 1983; Cannon et al. 1987; Fechhelm and Griffiths 1990). Three distinct modal groups occurred throughout the sampling seasons: young-of-the-year (YOY) at $\leq$ 100 mm FL, small juveniles from 100-200 mm FL, and larger juveniles and adults from 300-500 mm FL.

As shown elsewhere (Gallaway et al 1983; Fechhelm and Fissel 1988; Schmidt et al. 1991; Thorpe and Osborne, in preparation), YOY and probably some age-1 Arctic cisco are highly dependent on the prevailing easterly winds when they disperse westwardly as far as 650 km into Alaskan coastal waters to rear until maturity. Winds in 1990 prevailed strongly from the east, while 1991 winds were weak or westerly (see ***Environmental Influences on CPUE***). Consequently, the limited occurrence of YOY was reflected in the 1991 length distributions.

The modal group from 100-200 mm FL was prevalent throughout areas and periods for all years. By the end of the sampling season in September, YOY were included in the lower lengths of this intermediate group, as they would have grown to 140 mm FL by then (Fechhelm and Griffiths 1990). The strong presence of this group in all areas regardless of time or sampling suggests that it was present along the coast of the Arctic Refuge before the sampling season began and after the season ended. Based on available literature of Arctic cisco, juveniles overwinter in the Colville and Sagavanirktok rivers until they reach maturity at age 7 or 8 (Gallaway et al. 1983; Fechhelm and Griffiths 1990). Therefore, these juveniles may have already left the overwintering deltas to forage along the coast or they may have overwintered in deltas closer to or on the Arctic Refuge. Although the possibility of on-refuge overwintering areas for juvenile Arctic cisco was not addressed in this study, future research on the Arctic Refuge should include such work. Arctic Refuge rivers, i.e. the Canning and Hulahula, with similar winter conditions to the Sagavanirktok and Colville deltas, should also be considered for sampling.

The third distinct group of Arctic cisco, 300-500 mm FL generally appeared earlier in the season and gradually declined toward the end of the season. In 1990 for example, these fish were absent by September 1. Extensive movements of these larger juveniles and adults from coastal foraging areas to overwintering and/or spawning areas probably account for this pattern. These fish may have moved out of our sampling areas, especially in 1990, to locations with more tolerable levels of salinity and temperature. However, we found no consistent correlations between daily catch rates and environmental variables in our study (see ***Environmental Influences on CPUE***). Presumably, Arctic cisco have adapted to the highly variable Arctic environmental conditions and will maintain migratory patterns along the coast regardless of temperature and salinity. Consequently, migration and hence, catch rates would be less affected by temperature and salinity changes than would patterns of growth. Therefore, detecting changes in these growth patterns is an indication of the health of the Arctic cisco population. Future research should target temporal growth patterns and their changes.

Based on age and growth analyses, some of the larger individuals of this third group could have been mature adults (> 350 mm FL). The commercial fishery for larger Arctic cisco in the Colville River targets only larger juveniles before they reach maturity and the majority migrate back to the Mackenzie River to spawn as adults. However, some spawned-out fish have been caught in this fishery (Gallaway et al. 1983) and mature adults have been found in offshore Alaskan waters (Thorsteinson et al. 1990). Based on these findings, questions arise as to where these mature fish spawn and how extensively do they migrate into Arctic Refuge coastal waters.

Condition

Gender differences.— Mature Arctic cisco, mixed with feeding juveniles (some of similar size), migrate through the Arctic Refuge in July and are not available for sampling late in the summer. The mature migrating adult fish should have well-developed gonads and significantly heavier females may be more distinct in July than when only immature fish make up the available population later in the season. In light of the observed difference, future sampling designs for long-term monitoring should consider the variation due to gender. Continued separation of gender during sampling appears necessary if sampling early in the season. Sampling late in the open-water season may negate this need.

Seasonal differences.— One would expect Arctic cisco to increase in condition over the course of the open-water season as they store fat reserves for winter. Both increases and decreases in condition during the open-water season have been reported (LGL 1990). Recent research suggests that accumulating oils of Arctic cisco replace water (the reverse is also true) and changes in condition were not as pronounced as one might expect (LGL, personal communication). Eastward-migrating mature Arctic cisco, as discussed above, might also explain seasonal differences. Given the variability of the population size structure among seasons and years, the use of length intervals which are consistently present in all samples in the analysis of condition may allow long term monitoring. Additional study should be pursued regarding appropriate length intervals. Finally, comparative studies among years or areas should include samples from like seasons to minimize variation.

Overwintering.— Overwintering fish are expected to consume energy reserves during winter. A resulting decrease in condition would be expected, but is apparently not detectable by our methods. Oil-based energy reserves may be replaced by water, as discussed above, and may mask the effect of winter on condition.

Spatial differences.— Given the coastal dispersal and migration of this anadromous species between Alaskan coastal waters and Mackenzie river, differences in condition or slope were not expected, particularly early in the season. Spatial differences in condition, between various locations sampled, were not detected according to Whitmus et al. (1987), although they indicated that their and previous studies were biased by poor sampling regimes. In contrast, spatial differences were reported by Schmidt et al. (1989) when samples were measured in November during an overwintering study. More recent studies have not considered spatial differences in fish condition (Gallaway et al. 1989; Griffith et al. 1992).

In this study, differences in slope precluded examination of changes in condition in most cases. Changes in slope from one area to the next may indicate that equivalent stanzas, as discussed by Bagenal and Tesch (1978), were not available. This premise was supported by plots of transformed data. Limiting the analyses to length intervals that are present in all treatment groups may allow comparison of groups with equivalent slopes and enable more definitive statements about changes in conditions.

Annual differences.— Historically, observed year-to-year differences in Arctic cisco condition have been few. Whitmus et al. (1987) reported no differences among years, but reported that sampling regimes may have biased the results. Similar analyses by Gallaway et al. (1989) indicated no difference in condition, although more recent analyses highlighted significantly higher fish condition in 1989 compared to the four previous years (Griffith et al. 1992). Colonell and Gallaway (1990) concluded that few differences held biological significance.

In the current study several among-year condition differences were indicated when slope inequalities did not interfere with the interpretations. Annual variation appears to be an important source of variability and several causal mechanisms could be suggested. Cold water temperatures occurred in 1988 and 1991, low condition years (Figures 3.71, 3.73, 3.76, and 3.80) when the ice pack did not appreciably recede from the nearshore coastal waters. This contrasts with 1989 and 1990, high condition years, when warmer water temperatures and substantial ice pack withdrawal occurred. Ice pack and lower water temperature could affect fish condition by reducing metabolic rates, primary production, or currents responsible for upwelling and the transport of nutrients to nearshore habitats (Craig 1984; Gallaway et al. 1991). Until specific mechanisms are identified and can be accounted for by a separate variable, researchers should recognize annual variability as a major source of variation and consider it in study design, analyses, and interpretation of future comparative studies.

Age and Growth

The analyses indicate that the majority of Arctic cisco caught in Arctic Refuge coastal waters in July were juveniles from 0 to 4 years of age. These fish would be foraging along the coast after leaving overwintering areas in the Colville, Sagavanirktok or Refuge rivers or migrating to the west for the first time as age 0 or larger age 1 fish from the Mackenzie River. Arctic cisco reach age-13 in Alaskan waters although fish older than 7 or 8 years are rare in the Colville River fishery to the west. The presence of older adults in eastern Alaskan waters, suggesting foraging movements from the Mackenzie River area, should be investigated in future work.

Arctic cisco generally did not differ in length at age among areas or years. Spatial differences are difficult to detect in species such as Arctic cisco that migrate widely across most of the Beaufort Sea coast within a given year. In the one case where mean lengths did differ significantly, the sample size was too small and the variance too high to attach any biological significance to these findings.

Given the same population, detection of annual differences in growth rate is more likely since changes through time can be found more readily on a yearly scale. One pattern emerged from this analysis. At ages where mean lengths differed, 1991 lengths were smaller than those in 1989 or 1990. In 1991 the winds did not prevail from the east and the persistence of pack ice along the nearshore areas may have resulted in colder conditions which slowed growth. As indicated by our data, 1991 had colder water conditions (see ***Environmental Influences on CPUE***). However, small sample sizes make definitive interpretation of the data difficult.

In order to better determine spatial and temporal differences in growth for Arctic cisco, future research will have to implement considerably longer studies with simultaneous collection of physical and chemical factors. Long-term studies and larger sample sizes will help to detect differences in growth from environmental "noise" that is extremely prevalent in Arctic environments.

Movements

For small Arctic cisco westward movement in Arctic Refuge waters was documented by the recapture in the Kaktovik/Jago lagoon complex of fish marked in Beaufort Lagoon. Eastward movement is substantiated by the recapture in Pokok Bay and in the Kaktovik/Jago lagoon complex of fish marked in Camden Bay. While westward movement through Arctic Refuge waters to overwintering areas in the Colville and Sagavanirktok River deltas is expected, the observed eastward movement could be a result of westerly wind patterns.

Our inability to recapture any of the 919 Arctic cisco tagged and released in Arctic Refuge coastal waters during the 1988-91 field seasons was similar to past studies (West and Wiswar 1985; Wiswar and West 1987). These authors suggest that large Arctic cisco use the lagoons for brief time periods, before continuing their coastal movements toward the Mackenzie River, hence the lack of within-year recaptures in our study areas.

Our tag/recapture data indicate that these older fish are moving west as well. Assuming the eight Arctic cisco tagged in Arctic Refuge waters and recaptured in mid-October in the Colville were there to overwinter, they had all moved west instead of east as current theory holds. Thorpe and Osborne (in preparation) report that two adult (> 330 mm FL) Arctic cisco, one each tagged in Beaufort and Oruktalik lagoons in July and August respectively, travelled approximately 350 km before being recaptured in the Colville river three months later. These fish either overwintered in the Mackenzie River and moved west to Beaufort and Oruktalik lagoons then west to Colville (approximately 650 km) or overwintered in the Colville River the year before and made a round trip from there to the Arctic Refuge (approximately 760 km). Thorpe and Osborne (in preparation) hypothesized that older Arctic cisco found in Alaska waters may be nonspawners for those years. They suggest further work on Arctic cisco should target dynamics of the mature population.

Environmental Influences on CPUE: Arctic Cisco ≤ 200 mm FL

Past studies have suggested Arctic cisco are associated with less saline and/or warmer waters (Cannon et al. 1987; Fechhelm et al. 1989; Houghton et al. 1990). Our analyses did not generally support this premise as we observed no consistent patterns of association between daily catch rates of small Arctic cisco and physical variables in the 1989-91 data. While CPUE was most often negatively related to water temperature and positively related to salinity, the direction of these dependencies was sometimes reversed. The apparently contradictory results are undoubtedly a function of the large random error associated with the fyke net catches and the flexible behavior of the fish themselves. While more synoptic sampling efforts may help define preferential habitat use, the realized gain in information may not be directly proportional to the increased cost of a more extensive sampling regime. Movement of Arctic cisco (or any anadromous species) during the brief open-water period may be a continuous search for preferenda in a rapidly changing, heterogeneous environment, rendering the results from 24-hour passive gear sets of little use in determining "preferred habitat". An academic modeling illustration of this concept is presented by Neill and Gallaway (1989).

The determining force for observed distribution patterns of anadromous fishes in the Beaufort Sea remains uncertain. Arctic cisco may distribute themselves in response to prey distribution or immediate physical environmental cues, or some combination of the two (Gallaway 1990). Seasonal migratory instincts of anadromous fishes will also modify temporal and spatial trends of abundance and distribution within coastal waters, regardless of the thermohaline environment (Thorsteinson et al. 1990). Daily catch rates in Jago and Kaktovik lagoons in 1990 were much lower in early and late season samples, suggesting that a large pulse of transitory ciscos moved through the Jago/Kaktovik lagoon complex during early August. Linear trend analyses may be confounded by migration-mediated abundance patterns, whereas arbitrary subsetting of the data into temporal periods may bias results by artificially truncating potentially important information.

The existence of significant correlations between biotic and abiotic seasonal trends should be viewed with caution, however, as seasonal trends in daily catch rates of young Arctic cisco may be dominated by system-wide recruitment processes rather than localized environmental influences. Increased catch of small Arctic cisco in August was frequently observed, and is consistent with the hypothesis of a Mackenzie River origin for YOY Arctic cisco present in the Alaskan coastal waters of the central Beaufort Sea (Galloway et al. 1983). The lower numbers of small Arctic cisco caught in early summer were probably age 1+ and 2+ individuals which may have overwintered in Alaskan rivers and were thus present in Alaskan coastal waters throughout the summer (Fechhelm and Griffiths 1990). We feel a conclusion supporting a general flexibility of summer habitat use by Arctic cisco and other anadromous species is inferred by these and past Beaufort Sea studies. Development practices which may modify the early recruitment process of YOY Arctic cisco and/or degrade overwintering sites are most likely to impart detectable population perturbations.

Environmental Influences on CPUE: Arctic Cisco > 200 mm FL

Our results did not detect any strong or consistent relationships between daily catch rates of large Arctic cisco and available environmental variables. A weak general trend of higher daily catch rates during or shortly after periods of westerly winds was noted for many of the net stations, similar to observations in Prudhoe Bay (Fechhelm et al. 1989). West winds tend to pile up the warmer, less saline coastal waters against the shore, thereby narrowing their horizontal influence and extending them vertically. The result is a shoreward concentration of the coastal water mass. Adult Arctic cisco may often seek to remain in this relatively warmer water corridor, either for predatory or energetic reasons. A shoreward confinement of their movements or migration path would have resulted in the higher catches observed in our shallow water fyke net sets.

The migratory nature of Arctic cisco undoubtedly adds to the difficulty of determining preferred habitats during the open-water season. High daily catch rates of large Arctic cisco in the Beaufort Sea have been found in a wide range of temperatures and salinities (Cannon et al. 1987; Houghton et al. 1990; Thorsteinson et al. 1991). Some of these nondefinitive results attempting to delineate "preferred habitat" of anadromous fishes have often been explained as artifacts of mass movements by the fish to avoid suboptimal conditions or pseudo-random movements in a continual quest for a more favorable environment (e.g. Neill and Gallaway 1989). The majority of fish, primarily juvenile and mature non-spawners, are thus foraging along the coast during the brief open-water season while simultaneously maintaining a migration schedule which ultimately leads them either eastward or westward out of Arctic Refuge coastal waters. Thorsteinson et al. (1991) hypothesized that YOY Arctic cisco may modify their position along the coast in an effort to minimize loss of westward migration progress due to adverserial currents. Adults may similarly seek refuge in protected lagoons, with diminished regard for the thermohaline environment, if nearshore currents are antagonistic to an instinctual migration route. Such behavior may also influence nearshore daily catch rates during periods of westerly winds.

The use of offshore migration routes by YOY Arctic cisco was discussed by Thorsteinson et al. (1991) and suggests that shoreline fyke net data do not adequately address Arctic cisco distribution in the Beaufort Sea during the open water season. Inferences concerning movement in response to environmental cues are similarly weakened by this spatially truncated data. In our study, large Arctic cisco were more abundant in Simpson Cove during all years. The Simpson Cove net stations were also the most marine stations with respect to temperature and salinity and, perhaps most significantly, were located in a system most directly exposed to offshore water masses. Annual catch rates were lower in Beaufort, Jago, and Kaktovik lagoons, sampling areas which are more protected by barrier island complexes. These circumstances suggest that migrating large Arctic cisco do not confine themselves predominately to water masses most insulated from marine influence. Deflected coastal water masses and/or offshore currents favorable to migration routes may lead to significant numbers of anadromous fishes, including Arctic cisco, intermittently occurring outside the coastal corridor and the range of fyke net samples. This is parallel with the observations of Thorsteinson et al. (1991) regarding offshore catches of YOY Arctic cisco.

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